LIST OF POTENTIAL PROJECTS

Burt - 1. Production leveling - Optimum Inventory Program.

✓2. Balanced procurement (mathematical representation of parts lists, schedules and materials requirements).

✓3. Integrated plan for determination of order quantity, buffer stocks and delivery dates, reorder point (see Carnegie papers)

**4. Ordering plan designed to operate on actual needs rather than forecasted needs.

Tom 5. Make or buy.

✓6. Projection of usage for accuracy.

✓7. Re-write cost of carrying inventory.

✓8. Re-write cost of processing purchasing + internal orders.

✓9. Automatic dispatcher.

Tom - Geiser 10. Use of analog computer for load determination analysis (Production)

✓11. Use of risk--gain curve for determination of accepting inventory investments.

✓12. Write up reasons for and methods for obtaining Cost Reductions for Inventory Reduction.

✓13. Set-up computer program for ABC analysis.

✓14. Computer determination of labor input load projections (also material input material load).

✓15. Determination of effective measures of production control efficiency.

✓16. Set-up standard raw material code and dwg no. system

17. Conditions for and against lap phasing. - see Bothman work.

18. Prediction of Sales in terms of Mean and σ

✓19. determine E.O.Q. by Linear Programming.

✓20. establish a generalized factory model for dispatch rule testing.

21. Computer for Exploding P.L.'s ~~on~~ Considering multi-time period, intermediate stock, etc.

To H Waterhouse ✓22. Manufacturing Cycle Efficiency

23. Single Level vs. multiple level Steen explosion

24. Determination of material efficiency, labor efficiency, machine utilization efficiency.

(over)

IDEAS

The broad applications for vending machines incorporating data processing -

- Consider various cases where people buy information (not a product or physical service)
  - (1) tickets to plays, opera, sporting events, etc.
  - (2) transportation tickets
  - (3) Bank deposit + withdrawal
  - (4) Insurance policy issue (non-life)
  - (5) Credit vouchers (for merchandise purchase, etc.)
- consider cases where service is of a simple uniform product or physical service
  - (1) gasoline
  - (2) movie tickets
- Consider cases of ~~functional~~ product or product or service which are differentiated by customer selection criteria
  - (1) made to order cigarettes, cigars, coffee, etc.
  - (2) Sandwich making machine (not dispensing only)
  - (3) Blended paint, engraved wallets + *
  - (4) Size adjusted products: watch bands, rings, necklaces, bracelet
  - (5) Lipstick, powder, nail polish

SUGGESTED "HOW-TO-DO-IT" REPORTS

Economical Order Quantity

Bin Reserve

Fiscal Dating

ABC

Cost of Carrying Inventory

Cost of Processing an Order

Calculating Theoretical Turnover

Manufacturing Cycle Efficiency

Measurements for Materials Managers

Paperwork Processing

Receiving Routines

Raw Material Stockrooms

Planning a Punched Card Study

How to Make Physical Inventory Pay for Itself

Effective Filing - Terminal Digit

Reports -- Type and Appearance

In-Process Progress Reporting

To Stock or Not to Stock

Cycle Reduction Program

Inventory Control Program

B. GRAD
7/12/55

MANAGEMENT CONSULTATION
SERVICES DIVISION
GENERAL ELECTRIC

Ford —
pls return —
Burt
11/23

(2)

New York, November 11, 1954

Mr. Burt Grad
Room 2401
Building

Dear Burt:

As you know, the arithmetic of production explosions in the chain from final schedule back to orders on vendors amounts to matrix algebra. Aside from the elegance which one can have by using matrix notation there seems to be two ways in which the matrix point of view can make a real contribution.

How?

In the first place, when a change in final schedule is made, often the most pressing resultant change is that of notification of vendors. As usually done, these changes are the last available. The matrix theory indicates a way by which these can be immediately available.

Good

Secondly, the restrictions in capacity of various units of the manufacturing operation place restrictions on final model mix and volume which amount to linear inequalities involving the final model amounts. If, furthermore, a profit function is defined for the manufacturing organization, then we have an example of linear or non-linear programming, depending upon whether the profit function is linear or non-linear. Of course, the difficulty in applying the latter idea is in obtaining an explicit profit function. However, it should be possible in some cases to relate some of the objectives in a profit function, freeing managerial intuition to consider only the other intangibles. Here, again, our techniques bring us back to the need for education, and close liaison with Managers.

I should be glad to talk this over with you at any time.

Very truly yours,

Walt

WLMurdock/h

Vazsonyi paper.

Future ③

Inventory control -

Order Qty

A
B
C } classification by annual usage value
D - determined by infrequent usage - merely a protective reserve

A, B, C are subdivided into
A1, A2, A3
B1, B2, B3
C1, C2, C3

based on fixed to variable cost ratio -
The higher the Ratio the higher the Index no. assigned -
fixed cost is defined in terms of Equivalent set-up.

The order qty is established by mgt decision for each category -

A1 - 1 wk.
:
C3 - 52 wk. } many use { day
wk
mo.
yr

protective Stock

on each AB+C item a portion of the Stock is considered in the nature of a protective reserve stock. The size of this stock depends on the erraticness of demand. The Ratio of max period usage to avg period usage all divided by avg period usage ~~[illegible]~~ becomes the index number - When the items are arranged in descending sequence

X
Y } are used as a Classification code
Z

X - most erratic
Y - avg "
Z - least erratic

The previous ABC classification can be used to modify the XYZ code - for example a B or C item might be upgraded (from Y to X or Z to Y for example.) Correspondingly an A or high B might be downgraded.

The x y z will have assigned by mgt decision the amount of reserve stock for each category.

X - 120 days
Y - 60 day
Z - 30 day   as examples

Reorder pt = prot stk + procurement cycle

Procurement cycle depends on

actual vendor lead time
transportation time
paperwork processing time -
contingency reserves for
vendor or transportation delay
per variability

Classify as L - Long cycle
M - Medium cycle
S - Short cycle

again mgt decision sets the actual times for each category.

Batching lines; low items

terminable digits

discuss input-output media →

disposal of surplus inventory

usage computation

Mgt measures -

performance -

% of orders filled within stipulated time periods

% of items in protective stock range

% of items overstocked

max Inv = prot stk + ord qty

use 1.5 max Inv as check pt

no of items on Back order

Turnover A, B, C

Inventory $ -

clerical cost -

Daily Reports -

Qtrly analyses -

O.V. RI purchases -

The determination of how much to order
and when delivery should be made
and how much protective stock to carry

Now with good known production requirements week by week the quantity to order (since no price discounts are involved) should be directly tied the anticipated needs. However here the problem is how many weeks worth - Need a General Solution.

Del'y must be made in time for the first usage - so as to not go below the protective stk level -

Set Prot stk as a function of ABC —

#2 - Rm 212 4:15

1) Determining Reqts - consider variable lead time for different applications.

2) Establish desired protective stock

A items	1 day - 1 wk
B "	1 wk - 2 wk
C "	2 wk - 4 wk

3) Establish desired Order Quantity multiplier (Dely Qty)

A items	1 day - 1 week
B "	1 wk - 2 week
C "	2 wk - 8 wk

4) Ord Qty + Prot stk not to ever exceed Total Scheduled Requirements

5) Include Spoilage allowance + other uses in reqts computation.

6) Use Calculated planned balance as the start off figure.

→ clarify pg 5 - in this respect.

Demand part rate (wks)

" Ord Qty (wks)

Com elements — 2 choices: either use old schedule or have mach compute a new one based on certain rules

				Scheduled Deliveries ~~Purchases~~			Inventory Position
wk reqd in plant	Prod within hrs	other	Total	vendor code	P.O. #	Qty	
							+6 170
				218	850 921 ~~21 600~~	21 600	+12 950
6-21	15 820		15 820				+4 040
6-28	7 910	1 000	8 910	218	850 961	20 700	+4 075
7-05	20 655		20 655				
7 12	0	0	0				

machine Control test

Inventory position under old schedule -

If any — Balances or if too large plus balances - prepare new shipping schedule

What is Pur Cost

Cost of Carrying Inv

Internally mfd items

use same principle as for OV items - That is stipulating an OQM -

however, give more leeway possibly

+ calc

$$n = \sqrt{\frac{2U(S+P)}{CI}}$$

$$n = \sqrt{\frac{2(S+P)}{CI}}\sqrt{U}$$

$$\cancel{n = \left(\sqrt{\frac{2S}{CI}} + \sqrt{\frac{2P}{CI}}\right)\sqrt{U}}$$

for any pt - the higher the $\frac{S}{C}$ ratio is the larger should be the order qty -

To start might be arbitrary - apply only to C items - But select OQM on basis of $\frac{S}{C}$ ratio.

$$EOQ = \sqrt{\frac{2U(S+P)}{CI}}$$ internal parts =

depends on stability of U.

use A1, B1, etc to make plan feasible.

Sort of a slide rule

Usage = Reqts + (Inv desired − Inv actual)

Set up Reorder pt ...

Prot rth
Proc Cycle } Based on Usage

Purch pts – Successive Analysis at ea. price Breaking pt –

For ea item Eco Ord Qty can be estab for a given usage range.

Elec Sink + Cabinet. – Bill Breault

auto dishwash < 2 models – Sink / under counter.
Mobile Maid (portable dish)
disposal

Don Hughes.

Production Schedule

Appliance # ________

Week # 1
2
3
4
5
6
7
8
9
10

R = reqt'

R_{A01}

R_{A02}

⋮

R_{A13}

R^{011}_{A011}

R^{012}_{A012}

R^{013}_{A013}

R^{014}_{A014}

⋮

R^{034}_{A034}

R^{040}_{A040}

R^{010}_{A020}

R^{020}_{A120}

R = reqt'
A = product #
01 = month # - fiscal month
1 = week # within month -
if zero in last position indicates entire month

Specify 13 weeks + 9 months

③

T = time needed.

also have ~~SH~~ H = on hand as of start pt.

ea pt H_{010}

Raw Open Orders (incl. in transit)

ea pt. D_{011} qty to be delivered in what week – (to be completed by factory)

D_{012}

~~Shrinkage~~ ratio

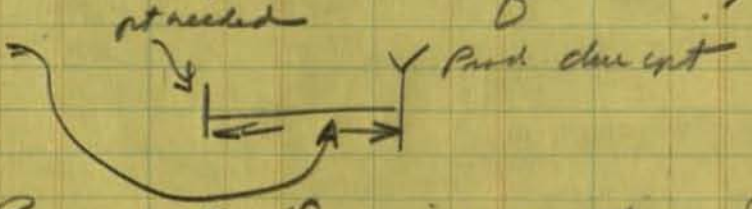
~~Spoilage~~ [illegible] =

$S = \frac{\text{Pts used} - \text{Pts needed}}{\text{Pts needed.}}$

~~S = 1 –~~ [illegible]

Lead time for ea application of each part

L = lead time ⇒



Ex

if buying Raw material includes time of Converting RM to finished parts ~~[illegible]~~

In addition we have a vendor procurement cycle call P_c

desired protective stock – call P_s.

Q_{01}^{A} Quantity of pt 01 used on Appliance A

First, what are needs in terms of qty + time

next, compare needs to availability.

Analysis for part 01 used in application A, B, C.

$$\left.\begin{aligned} Q_{01}^{A} \cdot R_{A}^{011} &= Q_{01}^{A011} \\ 011 - L_{01}^{A} &= T_{01}^{A011} \end{aligned}\right\}$$

$$\left.\begin{aligned} Q_{01}^{B} \cdot R_{B}^{011} &= Q_{01}^{B011} \\ 011 - L_{01}^{B} &= T_{01}^{B011} \end{aligned}\right\}$$

$$\left.\begin{aligned} Q_{01}^{C} \cdot R_{C}^{011} &= Q_{01}^{C011} \\ 011 - L_{01}^{C} &= T_{01}^{C011} \end{aligned}\right\}$$

$$\left.\begin{aligned} Q_{01}^{A} \cdot R_{A}^{012} &= Q_{01}^{A012} \\ 012 - L_{01}^{A} &= T_{01}^{A012} \end{aligned}\right\}$$

etc

$$S = \frac{\text{Pt used} - \text{Pt needed}}{\text{Pt needed}}$$

$$\text{Pt needed} \times S = \text{Pt used} - \text{Pt needed}$$

$$\text{Pt used} = \text{Pt needed}\ (S+1)$$

or $\text{pt to be used} = (1+S)\ (\text{Pt est to be needed})$

Sort by T carrying assoc Q along

T_{01}^{011}

$$\begin{array}{l} Q_{01}^{011} \\ Q_{01}^{011} \\ \text{etc} \\ \hline \Sigma Q_{01}^{011} \end{array}$$

yields total qty needed each wk for all applications

Q_{01}^{011} Q_{01}^{012} Q_{01}^{013} ... Q_{01}^{120}

$$H_{01}^{010} + D_{01}^{011} - \left[Q_{01}^{011}\right]\left[1+S\right] = H_{01}^{011}$$

if H is negative a pt order need is generated (N) for the quantity that H is negative so that the new $H = 0$

carrying a stp further -

$$H_{01}^{010} + D_{01}^{011} - P_S^{01} - \left[Q_{01}^{011}\right]\left[1+S\right] = H_{01}^{011}$$

$$H_{01}^{011} + D_{01}^{012} - \left[Q_{01}^{012}\right]\left[1+S\right] = H_{01}^{012}$$

etc

Every time that # goes negative an N is printed as other than zero

$$\left.\begin{array}{l} N_{01}^{011} \\ N_{01}^{012} \\ \vdots \\ N_{01}^{120} \end{array}\right\}$$

	WEEK No						
PT#	011	012	013	014	021	. . . .	120
01	N_{01}^{011}	N_{01}^{012}					N_{01}^{120}

Now the question is –

Do we place addl orders
modify existing orders.

if so, which ones + how much.

Also how introduce concept of non-fixed Schedule.
+ take into acct fraction of product year remaining

⑦

Simplest case is to assume no existing orders.

two extremes are 1) place orders for N_{01}^{011} to be delivered 011
N_{01}^{012} 012
etc 013
etc

2) place 1 order for $\sum_{w=011}^{w=120} N_{01}^{w}$ to be deld- in time to be meet 1st need.

infinite series of possibilities in between.

Could establish a Recommended Min Ord Qty
But would have to be based on a Usage figure - Not Realistic -

Could have a ~~table~~ ROQ in terms of no of weeks to buy at a time - sort of an OQ - So on discovery at 1st Need would examine next n no. of weeks add their needs together and place order for this qty on date of 1st need. Then cancel next N weeks of needs + look for next need.
might use A, B, C classification

or, Could assume an average Usage
$\mu = \frac{\Sigma N}{weeks}$ $U = 52\mu$ Then process with Sq root formulae -

with regt data avail it seems a shame not use it —

we could develop the OQM based on Eco Ord Qty formulae.

use Antic Yearly Usage × Cost/unit to classify A B or C

Then subclassify by

Q $\sqrt{\frac{[illegible](S+P)}{CI}}$ for internal pts

$\sqrt{\frac{P}{CI}}$ for ext parts – no price discount

$\sqrt{\frac{S_E+P}{C_E I}}$ where S_E is determined for usage range 1 wk to 1 yr —

Low valued first

High valued last

A1, A2, A3

B1 B2, B3

C1 C2, C3

Using trial examples determine optimum OQM for ea Category

Hence OQM's are only good then as long as U remains relatively fixed -

We could define Acceptable U Variation ± 25%

Must set upper limit restriction that $ROQ \leq \Sigma N$

might set up in terms of avg weekly usage-ratio vs. $\frac{\Sigma N}{\text{Weeks}}$.

How about Model change over plans.

Could be integrated by putting in new model usages sufficiently ahead of time if designs are available soon enough -

---

might determine $P_S^{o'}$ by formula also ——

Do not place orders in advance of Proc Cycle + time until next review

(10)

Data Needed

for a trial dept.

Pt #   Qty   PER APPL.   Lead time

---

must define Cost of Carrying Inventory ratio
Cost of processing an Order
Inherent variability of Schedule
next 1 mo
" 3 mo
" 12 mo.

---

if internal
Pt #   Cost/unit   Set up Cost

if external
Pt #   Cost at Qty   Qty

minimum ord qty
if any.

Better go thru step by step present routine for determining qty to order and delivery date -

Every purchase or mfg plan involves a certain cost

y = Total Cost

$$Y = \sum_{j=1}^{52}(n_j T_n + P) + \sum_{j=1}^{52} \frac{B_j \left(\frac{\sum n_j \cdot T_n}{\sum n_j}\right)}{52} C_I$$

where $\sum_{1}^{52} n_j + B_{j-1} \leq V$ where n_j indicates the qty ordered in the j^{th} week

~~N is fixed so that the summation does not exceed the anticipated usage next 12 months.~~

This may not be necessary if obsolescence function is properly determined

U = Antic usage next 12 months as derived from Production Schedule

C_I = Cost of Carrying Inventory ratio

B_j represents the Balance on hand as of the end of the j^{th} week.

A restriction probably will have to be introduced to show a surplus Inventory cost for any product remaining after the product year expires. If the product year expires early then a corresponding Inv Cost reduction should be made!

In effect the objective is to find that series of n_j's such that with the given B_{j-1}, and the R_j's given

Y is a minimum —

This poses a very large combinational problem and hence requires simplification.

• must assume some sort of relationship of order quantity from one time to another.

or establish a maximum order qty either in terms of weeks supply or an actual qty -

Conversely a min order qty might be set.

If annual ordering plan is to be continued
then price will not be a variable

This simplifies the ordering plan —
we are to specify delivery amounts
" dates

MAY BE A MAX DEL'Y QTY

should delivery qty be established in terms of
weeks of coverage (or days)

MAY HAVE PREFERRED MULTIPLES

Prot stk is dependent on

1) variability in product demand
over length of procurement cycle
2) Reliability of vendor promise
~~3) Length of procurement cycle~~
3) Cost of running out of Inventory
4) Cost of Carrying Inventory
5) Order Qty / yearly usage ratio

n_i = Order Qty = $\sum_{j=i}^{i+M} N^j$ $U = \sum_{j=1}^{52} N^j$

where M can take on Certain values

$$\underline{\underline{\text{14 values}}} \left\{ \begin{array}{ll} .1 & i \leq 520 \\ .2 & \\ .4 & \\ .5 & \\ 1.0 & \\ 2.0 & \\ 3.0 & \\ 4.0 & \\ 6.0 & \\ 8.0 & \\ 12.0 & \\ 16.0 & \\ 21.0 & i \leq \frac{52}{21} \\ 26.0 & i \leq 2 \end{array} \right.$$

let I = max value of i

Assume M to remain Constant during entire program

then $y = UR + -IP + \Big[H^{010} +$

Inventory picture

$H^{1} = H^{0} + D^{1} - R^{1} - P_{S}$

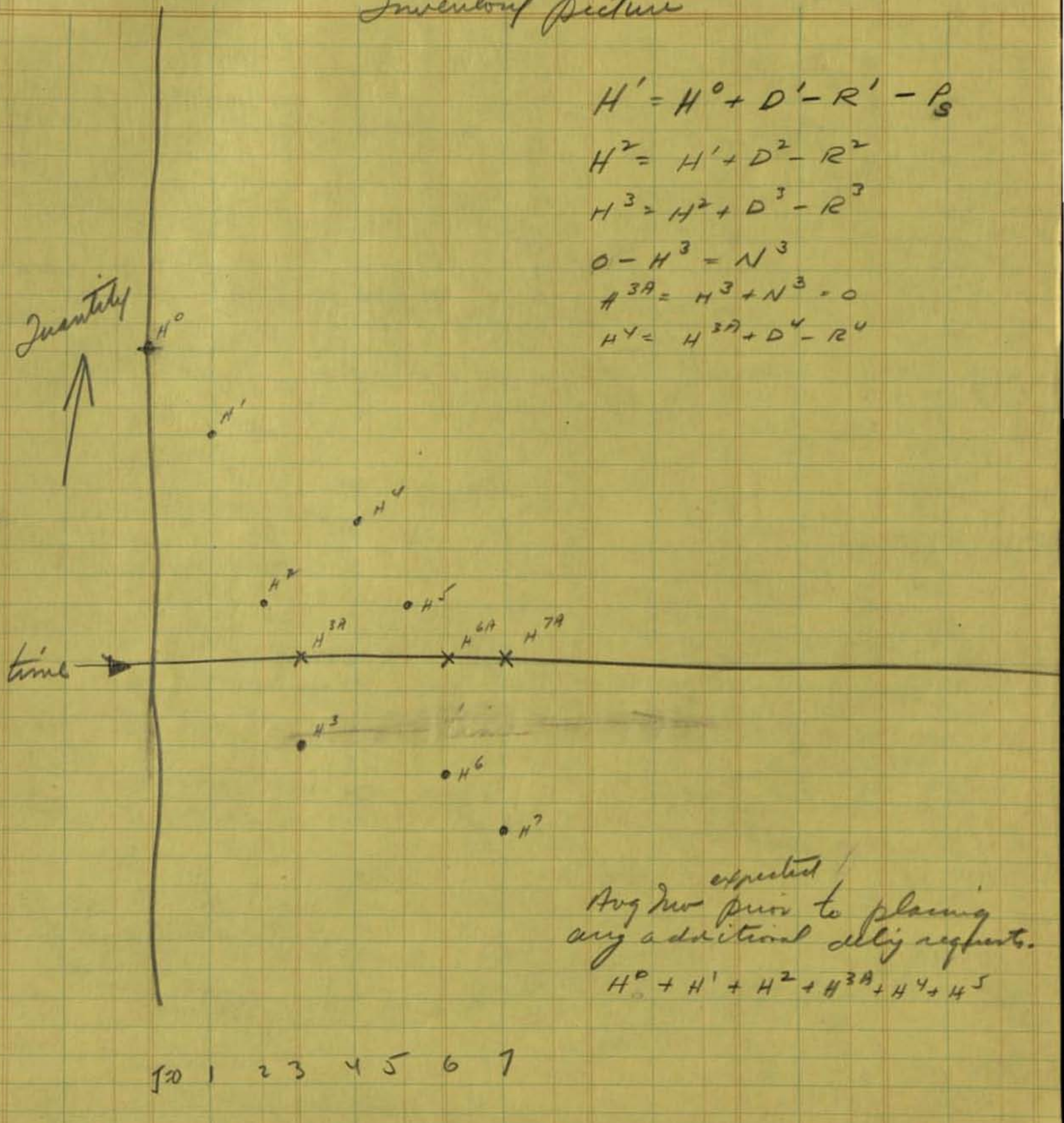
$H^{2} = H^{1} + D^{2} - R^{2}$

$H^{3} = H^{2} + D^{3} - R^{3}$

$0 - H^{3} = N^{3}$

$H^{3A} = H^{3} + N^{3} = 0$

$H^{4} = H^{3A} + D^{4} - R^{4}$



Avg Inv expected prior to placing any additional dlvy requests.

$H^{0} + H^{1} + H^{2} + H^{3A} + H^{4} + H^{5}$

Devise plan for creating a Schedule of Factory Requirements

Fabricated Part Record

Dept Loss Factor Mfg Lead Mtl class Unit of Issue

Prod Sched stg date Prod Sched No. Std Cost Description

Drawing number Record Date

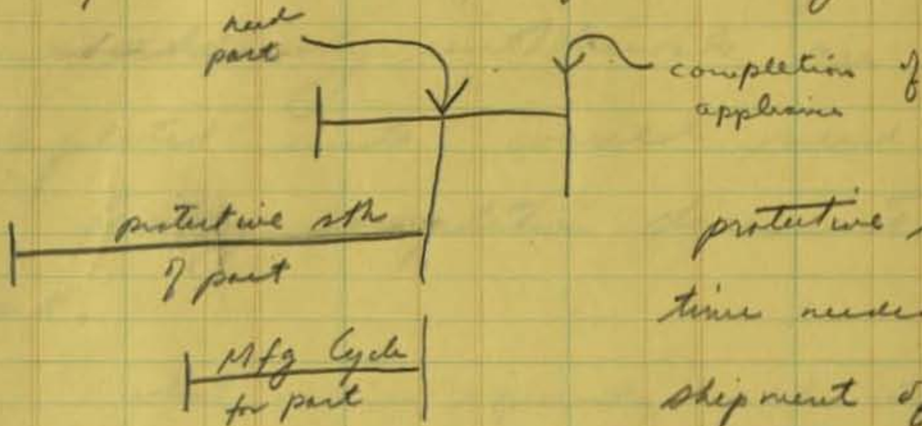
week stg Prod with loss other || Total wh Reqd cpt Cum Reqts

Order no.
Qty open
due cpt date

Purch pts

Prod other	out Qty	
1	1	A
2	2	B
4	4	C

mfg lead consists of two things



protective stock plus time needed prior to shipment of unit.

The part also has a mfg cycle (or procurement time)

→ If the assy cycles are short enough it may be possible to assume that all applications for a part have the same "mfg lead time" If this is so why bother using other than multiple week lead times.

Can a reorder pt principle be used with the Order qty determined by an Ord Qty multiplier. This OQM would be determined by ABC classification + subclassification by S/C ratio. The reorder pt would equal Prot stk + ~~Lea~~ Mfg cycle.

How can we keep track of where we are since the only withdrawals are in terms of completed units. would need some sort of factory completion document for each part.

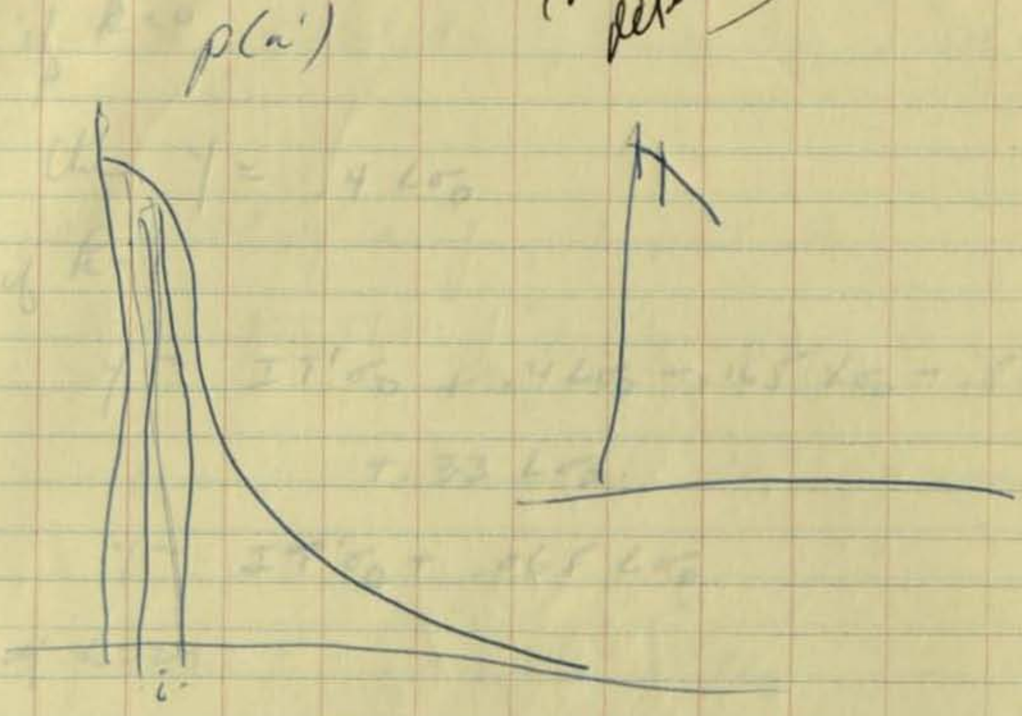
what routine is presently used to det when to order, how much to order, when to request delivery.

Must therefore maintain a stock record of sorts

No cpt tickets

Therefore must plan to operate on a total no. of parts not yet shipped.

Prot.
ath
determination



at

$n'' =$ interval no.

if $n'' = 1$

$n'_i = \frac{i}{2}$ where i = interval width

[illegible]

$\frac{C}{B+n'^2}$

if $k = 0$

then $y = .4 L\sigma_D$

if $k = 1$

$$y = IT'\sigma_D + .4 L\sigma_D - .165 L\sigma_D - .5 L\sigma_D$$
$$+ .33 L\sigma_D$$

$$y = IT'\sigma_D + .065 L\sigma_D$$

if $k = 2$

$$y = 2IT'\sigma_D + .4 L\sigma_D - .375 L\sigma_D - .5 L\sigma_D$$
$$+ .94 L\sigma_D$$

$$y = 2IT'\sigma_D + .465 L\sigma_D$$

~~$y = kIT'$~~

objective – minimize following Equation

$$kIT' + \int_0^\infty Ln' p(k) - \int_0^k Ln' p(n') + \int_0^\infty Lk\, p(n') +$$
$$\int_0^k Lk\, p(n')$$

Question: what is optimum point at the E_0
Carry

Y = Total Cost of carrying K point at the

$$y = KIT' + \int_{K/\sigma_D}^{\infty} L\cdot(n'\sigma_D - K)\, p_{n'\sigma_D}$$

where $p_{n'}$ = chance that $n'\sigma_D$ will occur

$$y = KIT' + \int_{\frac{K}{\sigma_D}}^{\infty} L p_{n'\sigma_D}\, n'\sigma_D - \int_{\frac{K}{\sigma_D}}^{\infty} L K p_{n'\sigma_D}$$

$$\frac{K}{\sigma_D} = \cancel{k}\, k$$

$$y = k\sigma_D IT' + \int_{k}^{\infty} L p_{n'\sigma_D}\, n'\sigma_D - \int_{k}^{\infty} L K p_{n'\sigma_D}$$

k	n'	$\overline{n'}$	$p_{n'\sigma_D}$		
0	0-1	.5	.33	$L\sigma_D \times$	.165
	1-2	1.5	.14		.210
	2-3	2.5	.01		.025
	3-4	3.5	.0001		
					.400

$$\int_{0}^{\infty} L p_{n'\sigma_D}\, n'\sigma_D \approx .4 L\sigma_D$$

$$\int_{0}^{\infty} L K p_{n'\sigma_D} = .5 L k\sigma_D$$

$\frac{dy}{dx} = IT'$ ~~ϕ~~ $- LC_{n'\sigma} =$

at $IT' = LC_{n'\sigma}$

$y =$ min

$K = T'$

$(n'\sigma - k)\, LC_{n'\sigma}$

$\mathcal{L} = f(n')$

$0 \leq n' \leq \infty$

$c \leq .5$

if $K = 1\sigma$

~~$dk = \frac{K}{\sigma}$~~

if $K = 0$

$C = .5$

$K = 1$

$C = .17$

n'	$C_{n'}$
~~1~~	~~.33~~
~~2~~	~~.47~~
~~3~~	~~.49~~
~~4~~	~~.5~~
0	.5
1	.17
2	.03
3	.01
4	.0001

$$y = UT^{*} + AIT' + NP$$

$$n = \frac{U}{N}$$

$$T^{*} = S^{*}/n + C^{*}$$

$$T' = \frac{S'}{n} + C'$$

$$A = \frac{n}{2} + R$$

$$N = \frac{U}{n}$$

$$y = \frac{US}{n} + UC + \left(\frac{n}{2} + R\right)\left(\frac{S'}{n} + C'\right)I + \frac{U}{n}P$$

$$y = \frac{RS'I}{n} + \frac{US}{n} + \frac{UP}{n} + UC + RC'I + \frac{S'I}{2} + \frac{C'nI}{2}$$

$$\text{if } \frac{dy}{dn} = 0 \qquad y = \text{min}$$

$$\frac{dy}{dn} = -\frac{RS'I}{n^2} - \frac{US}{n^2} - \frac{UP}{n^2} + \frac{C'I}{2} = 0$$

$$\frac{C'I}{2} = \frac{RS'I + US + UP}{n^2}$$

$$n^2 = \frac{2(RS'I + US + UP)}{C'I}$$

$$R = mU$$

$$n = \sqrt{\frac{2U(S+P) + 2RS'I}{C'I}} = \sqrt{\frac{2U(S+P+mS'I)}{C'I}}$$

call Florence have write-up

mailed to Merrill - air mail special

$y = U\overset{T}{\cancel{S}}$ [illegible] $+ A\cancel{I} + \overset{\cancel{\alpha}}{N}P$

$y = UT + AI + NP$

$T =$ ~~$\frac{S}{S}+c$~~ $\frac{S}{U/N} + C$

$A = \left[\left(\frac{U}{N}\right)\frac{1}{2} + R\right]\left(\frac{S}{n} + C\right)$

$\frac{dy}{dx}\left(Cx^r\right)$

$n = \frac{U}{N}$

$= rCx^{r-1}$

$Y = U\frac{S}{n} + UC + \frac{n}{2}I + RI + \frac{U}{n}P$

$x^2 \quad x^{-2}$

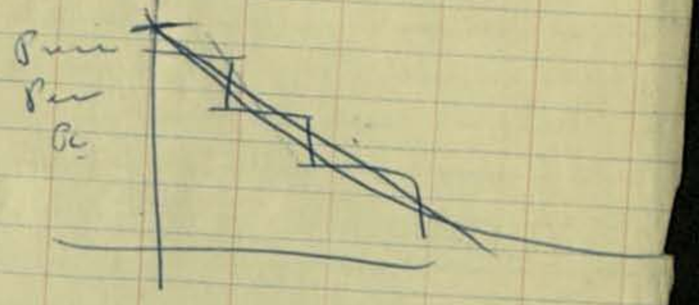
$2x$

$-2x^{-3}$

$Y = \frac{US}{n} + \frac{UP}{n} + \frac{nI}{2} + UC + RI$

if $\frac{dY}{dn} = 0$ then $Y = \min$

$\frac{dY}{dn} = -\frac{US}{n^2} \cancel{+} - \frac{UP}{n^2} + \frac{I}{2}$



U

$n = Q\sqrt{U} \rightarrow$ d

$U = f\{U\}$

mean = D σ = distribution

K = prot stk

if $\sigma = 0$ $K = 0$

if $\sigma > 0$

C = chance of D' occurring

L = Cost of losing 1 ~~sale~~ sale

$Y = KIT' + (D' - D) L c_{D'}$

$y = KIT' + (n'\sigma - K) L c_{n'\sigma}$

if $\frac{dY}{dK} = 0$ then y = min

if $\sigma = 1$

and $K = 1$

Loss = \$1 per unit

$$\sum_{n'=K}^{\infty} (n'\sigma - K) L C_{n'}$$

$$Y = KIT' + \int_{n'=K}^{\infty} (n'\sigma - K) L C_{n'}$$

$$\frac{dY}{dK}$$

Actual Loss = $L(D' - D - K) = L(n'\sigma_D - K)$

Extra Inv Carrying Cost = KIT'

where T' = Total Cost of item
I = Cost of Carrying Inventory
K = ~~Bad~~ Part Width
L = Loss per unit
D = mean demand
σ_D = std deviation of ~~mean~~ demand Curve
D' = $D + n'\sigma$

[illegible] $n' \geq 0$

D' = actual demand

Predicting future Reqts

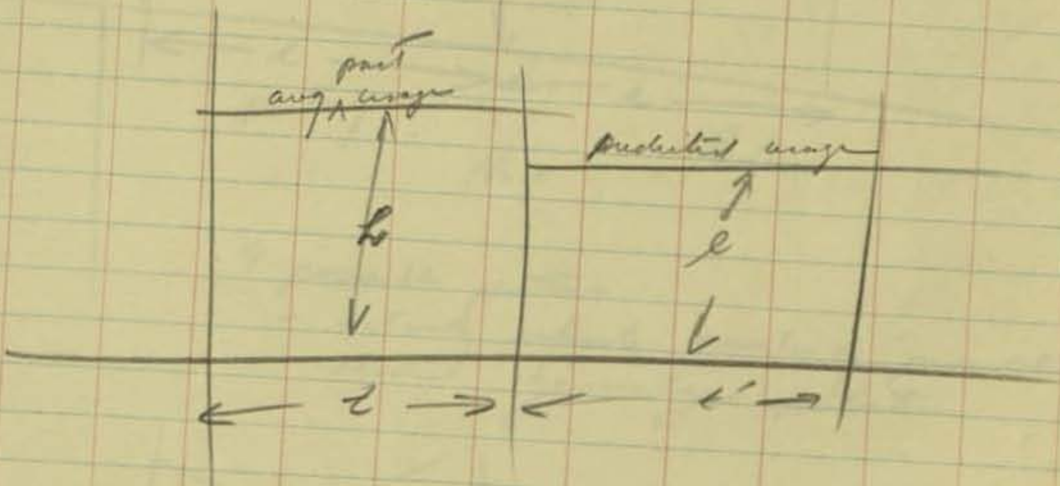
⑥

what factors influence prediction

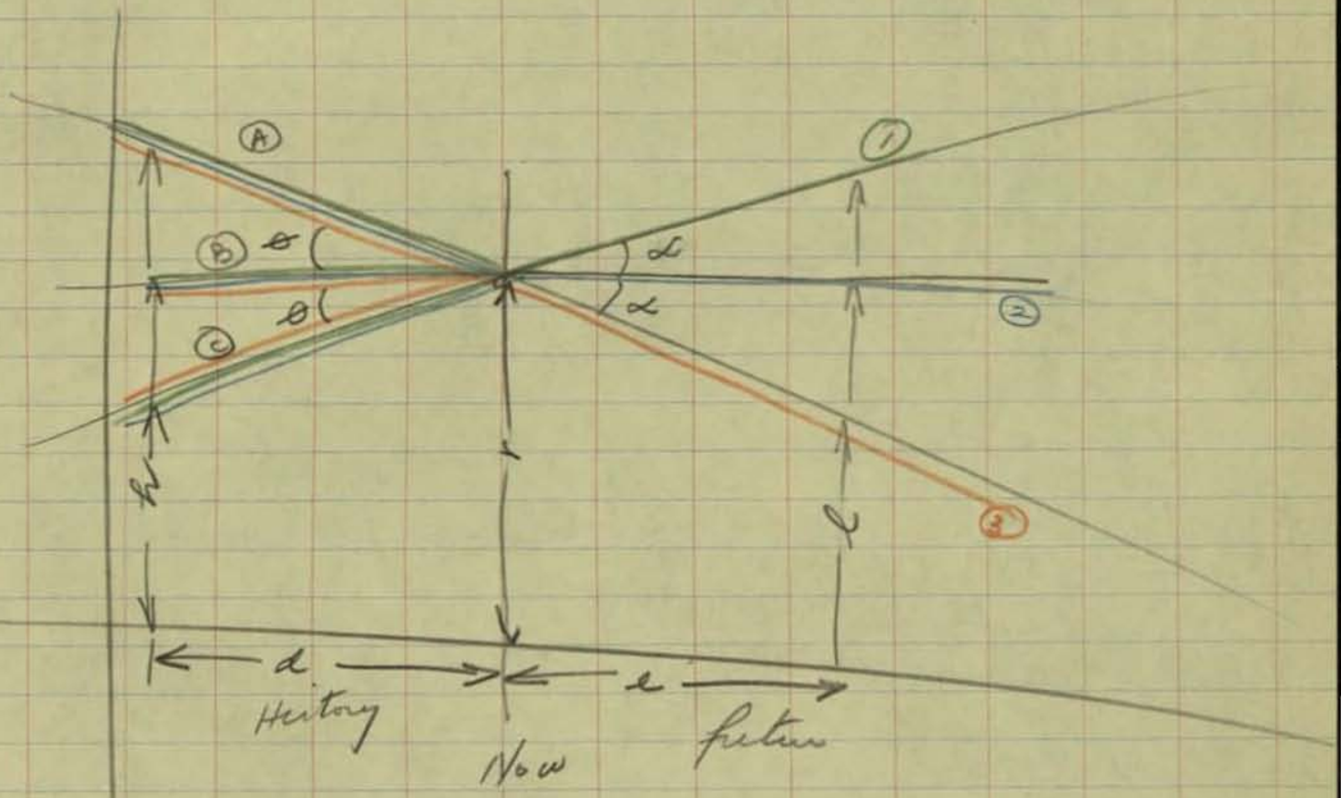
product mix
general sales picture + trend
characteristics of sales pattern (seasonal)
design change (model change)
material substitutions
spare parts needs

need to know causation for previous trend - the reason for ~~o~~

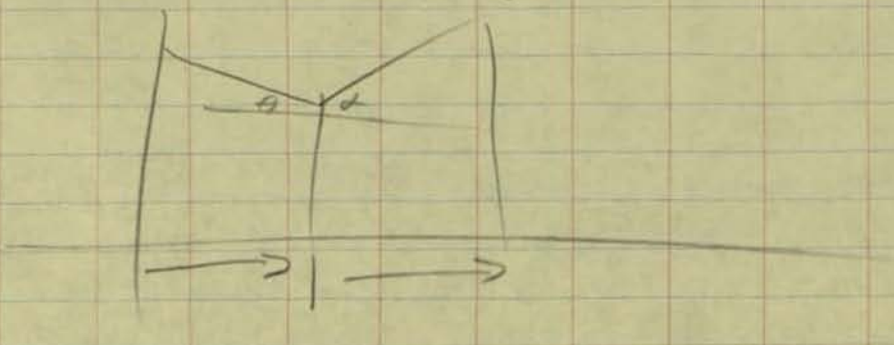
might be approached from an avg prediction



prediction of future requirements -



9 possible patterns
- actually infinite number of possibilities
need generalized solution



knowing -

α

h

θ — or get $\theta = f(r, h, \alpha)$

ⓡ - isn't $r = f(h, \theta, \alpha)$

predict -

l for a given a

$\alpha = f(l, a, r)$

must predict statistically logical answer

— patterns possible

A1 } have sign wave characteristics
C3

A3 } straight line approx
C1
B2

A2 } need hyperbolic or parabolic function
C2
B1
B3

Keep Your Inventory Carrying Costs Down

By R. C. Hartigan and B. Grad
Turbine Department
General Electric Company

What does your inventory cost you?
How can you cut your overhead and increase profits by inventory control? To make the most effective business decision, it is vital that you know the cost of carrying inventory for your plant. Here is how.

WHAT DOES your inventory cost you? How much can you reduce your overhead and increase your profits by controlling your inventory level?

To make the most effective business decisions it is vital that you know the cost of carrying inventory for your plant. The following method for determining this cost introduces a somewhat different approach and should encourage you to investigate its application in your own plant.

The cost of carrying inventory will generally consist of four basic factors:

- **I. Possession Costs**
- **II. Value Losses**
- **III. Return On Investment**
- **IV. General Business Influences**

In determining inventory carrying costs you should consider only those costs which are chargeable to inventory, those which vary with a change in inventory level independent of a change in output. In evaluating the effect of each factor this question must be answered; "What can be done with the facilities and funds made available by reducing inventory?"

The nature of the product and the overall economic conditions will affect the evaluation of the four key factors. You will, of course, be accounting for the nature of your product when you evaluate these factors in terms of your own business. In the following analysis you will find that each factor has been considered in the light of three common economic conditions:

1. Conditions poor—market poor—expansion not desirable.
2. Conditions good—market good—expansion restricted by lack of floor space.
3. Conditions very good—market very good—expansion vital to maintain position in the field.

For simplification, it can be assumed that under conditions 2 and 3 there is a productive use for money freed by reducing inventory and that it will earn the present return on investment.

Factors Which Determine Cost of Carrying Inventory

I. Possession Costs—Those costs chargeable to inventory which are normally considered part of overhead.

Space

Economic condition 1—Productive space made available by reducing inventory would not be utilized because no market is available for increased output. Cost of space chargeable to inventory is zero because an inventory reduction does not affect the cost of space. If consolidation into fewer buildings is possible, the cost chargeable to inventory will be interest on the resale value of buildings vacated.

Condition 2—Space made available by reducing inventory would be utilized for increased output. Since inventory ties up this space, the cost chargeable to it is the cost of equivalent floor space equal to the area occupied.

F = Cost per year of present floor space in \$/sq.ft./yr.
A = Area occupied by inventory in sq. ft.
I = Value of inventory

$$\% \text{ Cost} = \frac{FA}{I} \times 100\%$$

Condition 3—Expansion will take place, thru new construction if necessary. Reduction of inventory will avoid construction of new space or reduce the amount required. In effect, the cost of space was reduced by reducing inventory. The cost chargeable to inventory is the cost of additional space equal to the area occupied. Cost of utilities is included here because heating and lighting of new space is also avoided.

U = Cost of utilities in \$/sq.ft./yr.

$$\% \text{ Cost} = \frac{(F + U)A}{I} \times 100\%$$

Equipment—Cranes, vehicles, bins and racks.
Condition 1—Inventory reduction would permit the sale of part of this equipment because less equipment is required to handle less inventory. Money obtained from this sale would not be reinvested because the market will not support it. Cost is therefore the interest which could be earned on the resale value of the equipment.

V = Resale value of equipment in \$
R = Interest rate in %/yr.
I = Value of inventory in \$

$$\% \text{ Cost} = \frac{VR}{I}$$

Condition 2—If floor space were available, additional equipment would be obtained to support expansion. Since we can avoid purchase of new equipment by reducing inventory, the cost is the equivalent of the yearly depreciation of existing equipment.

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D = Cost of equipment in \$/yr. (Depreciation)

$$\% \text{ Cost} = \frac{D}{I} \times 100\%$$

Condition 3—Additional equipment will be obtained to support expansion. Cost is the equivalent of yearly depreciation of existing equipment as in Condition 2.

Handling

Conditions 1, 2 and 3—Under any conditions handling labor is proportionate to the inventory level. Cost chargeable to inventory is the sum of all material handling labor expense. This includes crane operators, crane followers, fork truck drivers, stock room handlers and move men.

H = Total handling labor expense in \$/yr.
I = Value of inventory handled

$$\% \text{ Cost} = \frac{H}{I} \times 100\%$$

Insurance

Two types of insurance costs must be considered. First, consider those costs based directly on floor space, such as fire insurance on buildings:

Conditions 1 and 2—Cost chargeable to inventory is zero because insurance would be paid on this space whether it is occupied by inventory or not.

Condition 3—Additional floor space would make additional insurance necessary. Cost chargeable to inventory is the cost of insurance on the area occupied.

D = Cost of floor space insurance in \$/sq.ft./yr.
A = Space occupied by inventory in sq.ft.
I = Value of inventory on the area

$$\% \text{ Cost} = \frac{DA}{I} \times 100\%$$

The second type of insurance cost is that based directly on inventory value, such as fire insurance on inventory.

Conditions 1, 2 and 3—The cost is obviously the cost of insurance.

D = Cost of insurance in \$/yr.
I = Value of inventory insured

$$\% \text{ Cost} = \frac{D}{I} \times 100\%$$

Taxes

As with insurance the same two types of taxes must be considered. For those based on floor space such as real estate tax:

Conditions 1 and 2—Cost chargeable to inventory is zero because taxes would be paid on this area whether occupied by inventory or not.

Condition 3—Additional floor space would increase taxes. Cost is the tax expense on the area occupied.

S = Tax expense in \$/sq.ft./yr.
A = Space occupied by inventory in sq. ft.
I = Value of inventory on the area

$$\% \text{ Cost} = \frac{SA}{I} \times 100\%$$

The second type of tax expense is that based on inventory.

Conditions 1, 2 and 3—The cost chargeable to inventory is the cost of taxes.

T = Tax expense in \$/yr.
I = Value of inventory taxed

$$\% \text{ Cost} = \frac{T}{I} \times 100\%$$

Cost Of Taking Physical Inventory

Conditions 1, 2 and 3—The cost depends only on the inventory level and is not directly affected by the economic conditions. Cost chargeable to inventory is the cost of taking inventory.

P = Cost of taking physical inventory in \$/yr.
I = Value of inventory

$$\% \text{ Cost} = \frac{P}{I} \times 100\%$$

II. Value Losses

Decrease in value of inventory due to one of the following factors:

Obsolescence

Conditions 1, 2 and 3—Obsolescence is the chance that a part will become unusable due to engineering changes and is not directly affected by economic conditions. It is determined by two factors:

p = Percent chance that design of any part will change in one year.
i = Percent chance that parts will be affected by that change.

The factor "i" accounts for the possibility that a part may be used before the change is effective. For an established product "i" will be relatively low since most changes are of an improvement nature and are incorporated with a minimum of obsolescence loss. For a product in the development stage where engineering changes are in the nature of design corrections "i" will be relatively high because the desirability of using a part is frequently overridden by the urgency of the change.

Obsolescence = i p = % Cost

Alternate Method of Evaluation—If records of actual dollar losses due to obsolescence are available, the following is an easier and more accurate method of evaluating costs chargeable to inventory:

O = Obsolescence losses in \$/yr.
I = Value of inventory

$$\% \text{ Cost} = \frac{O}{I} \times 100\%$$

Natural Deterioration, Loss and Damage

Conditions 1, 2 and 3—These value losses include repair and replacement costs of those parts which have been lost, damaged or made unusable by such natural forces as moisture. They do not depend on economic conditions. Although loss and damage are probably negligible in heavy industry, such commonly accepted practices as the sandblasting of rough castings to remove rust are actually repair operations made necessary by natural deterioration.

V = Repair and replacement costs in \$/yr.
I = Value of inventory.

$$\% \text{ Cost} = \frac{V}{I} \times 100\%$$

III. Return on Investment

Net profit earned expressed as a percentage of the investment.

Condition 1—Dollars freed would only be used to earn the going interest rate since the market will not support reinvestment and expansion. The cost of potential gain chargeable to inventory is the interest which could be earned on the inventory value.

R = Interest rate in %/yr.
% Cost = R

Conditions 2 and 3—The dollars freed by reducing inventory would be reinvested in the business and earn the return. Cost of potential gain is therefore the return on investment earned by the business.

T = Return on investment in %/yr.
% Cost = T

IV. General Business Influences

Cost Improvement—Reduction in costs due to technological improvements. This is generally accepted as a steady trend regardless of business conditions at about 3%.

This figure should be higher for a new business.

% Cost = 3%

Value of the Dollar

Condition 1—This condition indicates a deflationary trend. Inventory purchased this year would cost less next year. Cost chargeable to inventory is the yearly decrease in first cost.

	ECONOMIC CONDITIONS		
	1	2	3
I. Possession Costs			
Space	0	1.4	1.9
Equipment	.1	1.0	1.0
Handling	3.7	3.7	3.7
Insurance	.1	.1	.2
Taxes	.6	.6	1.6
Cost Of Taking Inventory	.5	.5	.5
II. Value Losses			
Obsolescence	.8	.8	.8
Deterioration	1.2	1.2	1.2
III. Return On Investment	4.0	20.0	20.0
IV. General Business Influences			
Cost Improvement	3.0	3.0	3.0
Value Of Dollar	3.0	0	-3.0
	17.0	32.3	30.9

CARRYING COSTS in per cent per year of inventory value.

C_B = First cost at beginning of the year
C_E = First cost at end of the year

$$\% \text{ Cost} = \frac{C_B - C_E}{C_B} \times 100\%$$

Condition 2—This condition indicates fairly stable prices. Cost is therefore zero.

Condition 3—This condition indicates an inflationary trend. Inventory purchased this year would cost more next year. Since this is actually a savings the cost figure becomes minus and is the yearly increase in first cost.

$$\% \text{ Cost} = \frac{C_B - C_E}{C_B} \times 100\%$$

Clerical and management costs are sometimes considered a cost of carrying inventory. A reduction of these costs in some operating sections will result from inventory reduction. However, this inventory reduction is only obtained by increasing clerical and management costs of the control functions such as inventory control, machine loading, etc. There is probably no net change in clerical and management costs as a result of reducing inventory.

An accurately determined cost of carrying inventory, revaluated periodically to account for changing costs, can be applied to:

1. Accurately predicting changes in costs with change of inventory level. Cost reductions may be based on savings resulting from reduced inventory.
2. Determining the desirability of carrying stock inventory. By separately evaluating the costs of carrying stock and non-stock inventories those additional costs incurred by stock can be determined.
3. Recommending disposition of surplus and obsolete inventory. The cost of continuing to carry this inventory once it is on hand will depend on the resale value because full value cannot be realized.

What does your inventory cost you?

COST OF PROCESSING AN ORDER

In examining the costs related to the processing of an order, a certain viewpoint must be established. It involves looking at the problem from the following standpoint -- which costs are directly assignable to the number of orders placed or processed and which costs are dependent upon the size or complexity of the order. This means that certain costs which are definitely part of the processing charges must be ignored, since they are not controlled by the number of orders placed. Certain examples of this include 100 percent inspection, foremen's duties, supervisory responsibility and general overhead.

Therefore, in this analysis we will consider only those charges which are directly assignable to the existence of an individual order. These charges can normally be broken down into four phases:

1. Origination of the order
2. Processing and/or procuring the material
3. Storing and disbursing
4. Recording and paying

As a further sub-division, it will frequently be advisable to break down your orders into the following types:

1. Outside vendor
2. Contributing division
3. Allied plant
4. Internally machined
5. Combinations of the above

Where a problem of ordering both stock and non-stock material exists, you may want to make a further breakdown into these two headings.

On the attached page are listed some of the factors which must be considered in evaluating the cost of processing an order for a specific department.

These are two ways of establishing these detailed costs. The first which might come to your mind is to use some sort of a time study approach whereby you actually examine how much time it takes, as an example, for an order clerk to write one order card, multiply this by his hourly rate and come up with the cost of writing one order. However, it has been found that a second approach seems more realistic. This involves the accumulating of output data from each of the various functions. These output figures, taken over some period of time as, for instance, a month or a year, are then divided into the total amount of money spent for that activity during this same period. These data are readily available in most departments and benefits are obtained just from the analysis alone. For instance, in Steam Turbine it enabled them to specifically allocate every person's activities to a particular function associated with the processing of an order.

The existence of these data should serve in the following ways. First, as aiding in the decision of an economical order quantity to purchase or manufacture. Second, as a guide to areas of potential cost reduction; and third, as control figures to supervision to enable them to compare their own standings to that of the department as a whole.

B. Grad
Production Control Section

9/8/53

CHARGES ASSIGNABLE TO AN INDIVIDUAL ORDER

Outside Vendor

1. Originate
    - a. pull order cards from P. L.
    - b. write order, mark PL
    - c. type 3x5 hecto master
    - d. duplicate paperwork
    - e. distribute paperwork
2. Process and Procure
    - a. place and expedite order by Purchasing
    - b. maintain progress file
    - c. file stockroom P. W.
    - d. maintain Receiving File
    - e. expedite order by Production
    - f. Receive
    - g. Inspect and Lab Release
    - h. Deliver to stockroom
3. Store and Disburse
    - a. Place in location
    - b. Store
    - c. Accumulate
4. Record and Pay
    - a. Authorize payment
    - b. Pay (Accounting)
    - c. File (Cost)

Internally Machined

1. Originate
    - a. pull order cards from P. L.
    - b. write order, mark PL
    - c. type 3x5 hecto master
    - d. duplicate paperwork
    - e. distribute paperwork
2. Process and Procure
    - a. attach blueprint
    - b. Plan
    - c. type or dupl. vouchers
    - d. maintain progress file
    - e. file stockroom P. W.
    - f. maintain Prod. Index File
    - g. Expedite order by Prod.
    - h. Deliver to factory
    - i. Dispatch
    - j. Move in factory
    - k. Follow Prod. in factory
    - l. Inspect
    - m. Deliver to stockroom
3. Store and Disburse
    - a. Place in location
    - b. Store
    - c. Accumulation
4. Record and Pay
    - a. Pay (Payroll & Time-keeping)
    - b. File (Cost)

DRAFT

DISPATCHING BY COMPUTER

It is visualized that an electronic computer could perform many of the operations currently assigned to factory dispatchers. A list of dispatchers' duties might include:

1. Maintenance of a file indicating the present location of each part in the factory.
2. Maintenance of a file indicating the operations still to be performed on any part.
3. Maintenance of a file indicating which parts are in operation.
4. When requested to do so by an operator to assign a job or jobs to that operator which are in accordance with the station at which he works and the operator's individual ability.
5. To direct the material movement in transferring parts from one location to another.
6. To validate vouchers.
7. To forewarn foremen and production supervision of excessive loads at any station or group of stations.
8. To process the paperwork necessary to correct the files when authorized by an inspection report or an ~~Authorization~~ Alteration Notice.
9. To maintain a deadload of jobs coming into the factory so that future loads might be predicted.
10. To obtain blue prints for the operators. and detailed planning sheets
11. To arrange for the preparation of continuation vouchers where needed.
12. To advise production expeditors when requested as to current parts ~~stocks~~ status.

In order to accomplish these functions, it would be necessary for the computers to have combination input and output devices at various factory locations. This should provide for the operator to key in his pay number and station (this could be automatic through an Addressograph type device) as well as the drawing number of the job which he has completed and the number of pieces completed. The device should provide him with a voucher for that part which he should work on next. The central computer would require in its memory the following information:

1. The detailed planning of each part indicating each station through which it goes indicating the time per piece at that station and the caliber of employee required to do the operation.
2. A record as to the physical location of each part at the present time.
3. A record of capacities of each machine.

It would probably be undesirable for the machine to produce either a blueprint or a detailed planning sheet (the operation description) for the operator's use. Therefore, it is postulated that both of these documents would be of such a form as to travel directly with the material itself from station to station.

There would of necessity be certain auxiliary equipment at the central point of the computer which would provide the payroll section with a voucher so that the man might be paid and a progress report so that production would know where various parts were located. It should be possible to accumulate total loads for a limited future period through auxiliary sorting equipment.

It is visualized that the machine would have to work at high speed, but this might be reduced considerably by the machines precalculating what job to give each operator before the operator asks.

The discussion has been centered on the requirements of a job shop but might be applied to a lot or flow type area. No estimates are included as to anticipated costs as this would depend primarily upon the department being studied. It is suggested for survey purposes that a large department such as

Large Steam Turbine-Generator or Motor-Generator be studied.

It is my recommendation that a study team be organized consisting of one advanced manufacturing trainee and one very well experienced dispatcher who would function under my guidance in preparing a detailed survey as to the costs and savings to be realized from developing an electronic computer for dispatching.

Burton Grad
6/17/54

BG:D

Each job would have to have a classification as to operator calibre required (A, B, C)

The operator on approaching the unit inserts his card – (name, pay no, calibre, station #(?)) machine has in immediate memory the top priority job or jobs (up to h no. of hrs planned work) for each stn for ea calibre employee. The employee will receive a three part form (punched or typed) with – Dwg + pt #, qty of parts, location in factory, 12 digit desc of operation location to be moved to upon completion price per unit, set up price if any – with the job would be the B/P + Plug Record – one copy of voucher is move ticket, one copy is operator's receipt one is pay voucher(?) to be turned in

Saving on voucher preparation, pre typing get a punched card voucher automatically for payroll + cost.

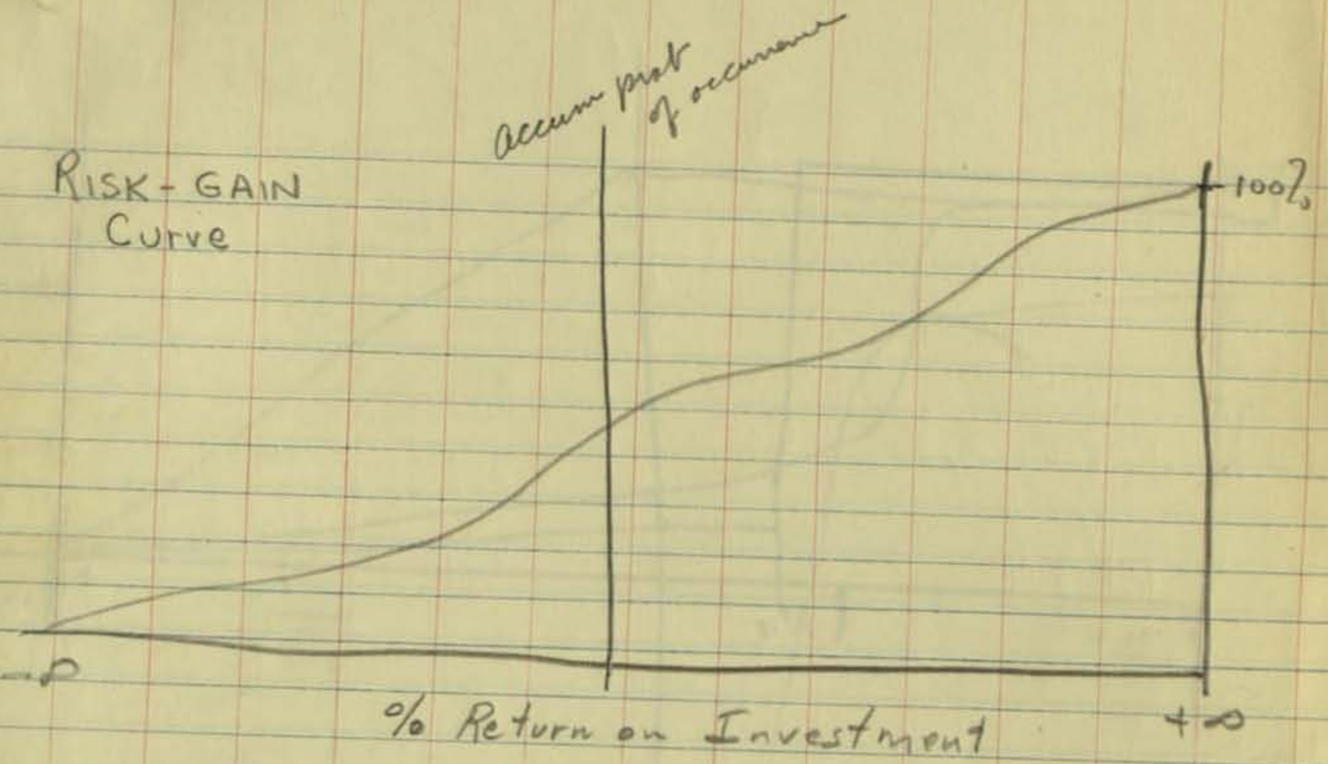
The basis of job selection would be a priority system based on cpt date, work left to be performed and avg flow time - Rush jobs could be given overriding negative priorities - Supplies for example might get an automatic bonus of -20 pts - The assignment of overriding priorities would have to be closely controlled by the prod Supv

→ The Order Card itself would be sent to the Central Computer Office where it would be entered on a dead load tape. This dead load tape would be sequenced at regular intervals by due start date.

not necessarily coded by days or S.O.

Upon Receipt of RM ~~[illegible]~~ a RM avail ticket would be forwarded to the computer unit where an appropriate notation would be made on the Dead load tape indicating that release to the factory was permissible as well as location of material all jobs using Ros carried on stock would have been coded properly upon initial entry to the Dead Load Tape × Each week those jobs due to be started during the succeeding week would be selected from the Dead load tape ___ . This new tape would then be used to select from the Operation + Plng File tape the material + labor needed. This would then permit the printing at the specific remote station on appropriate release form - probably 2 copies one to serve as an ID tag + 1 to be inserted in mail as notification of release or unavailability × If released the delivered to location would have been noted These jobs are then added to the Live Load tape + a priority II calculated

RISK-GAIN
Curve

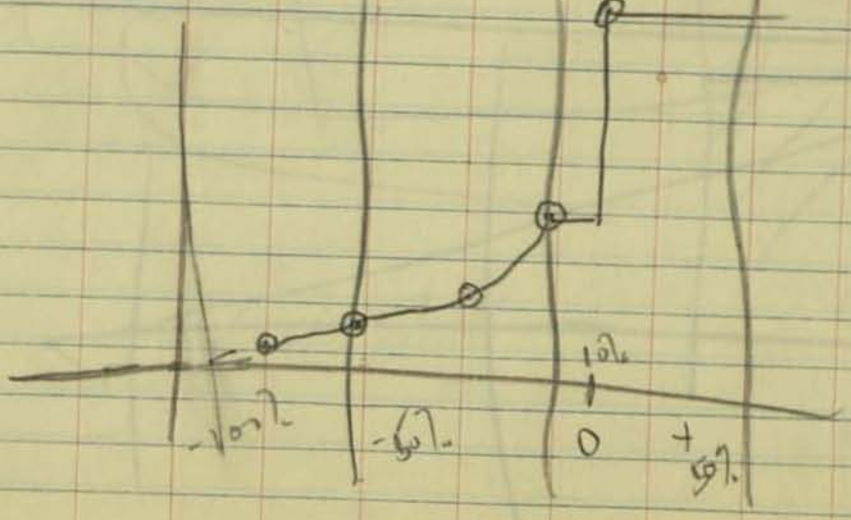


Objective of Investing funds

Within definitive limits of
Risk & Gain potentialities
Choose that Investment which will
Minimize The area under the Curve

---

proposal: Invest $100 in Stocking Ball Brg # XYZ
object: Draw Risk Gain Curve

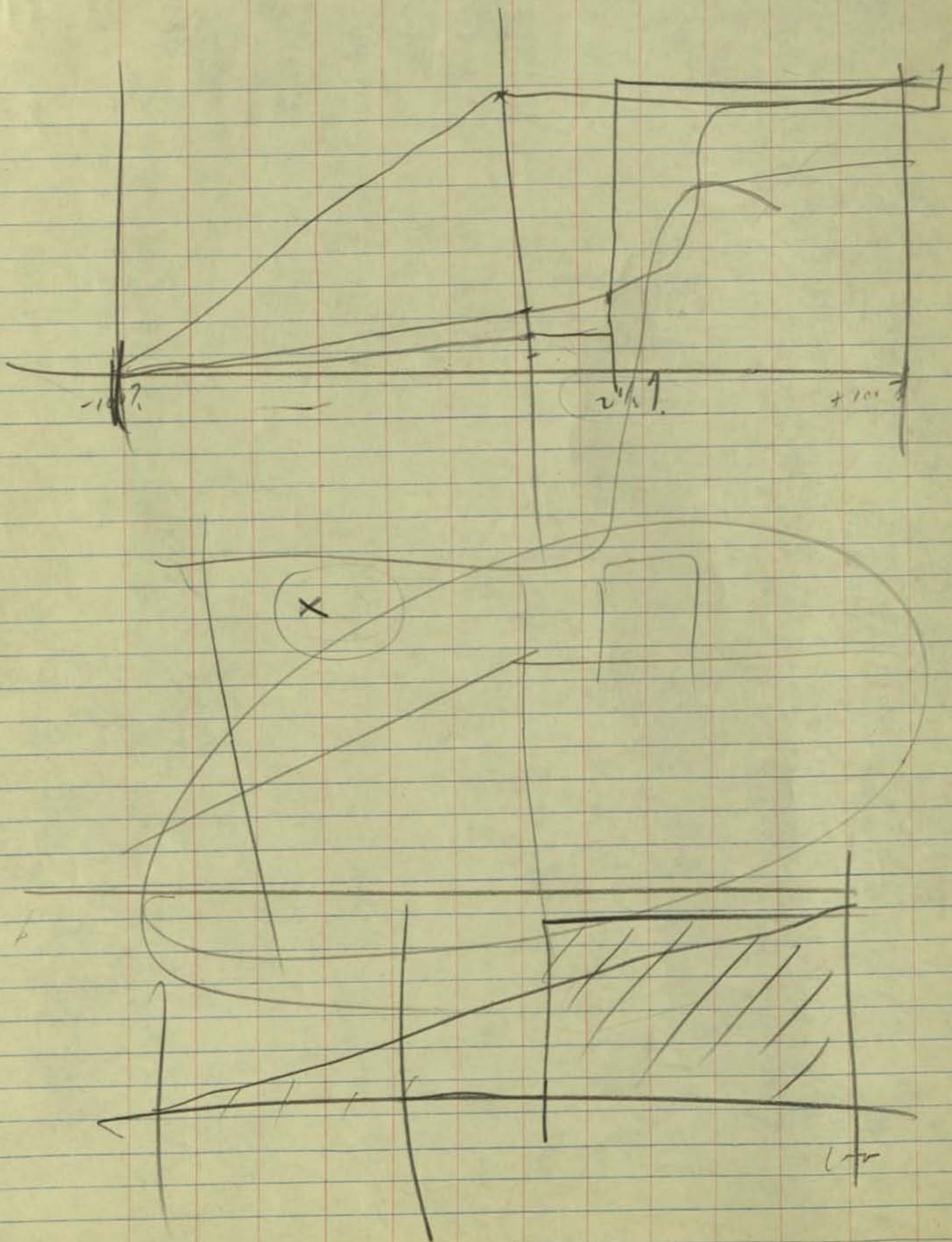


facts: current usage
= $7 per week

prob design obs -

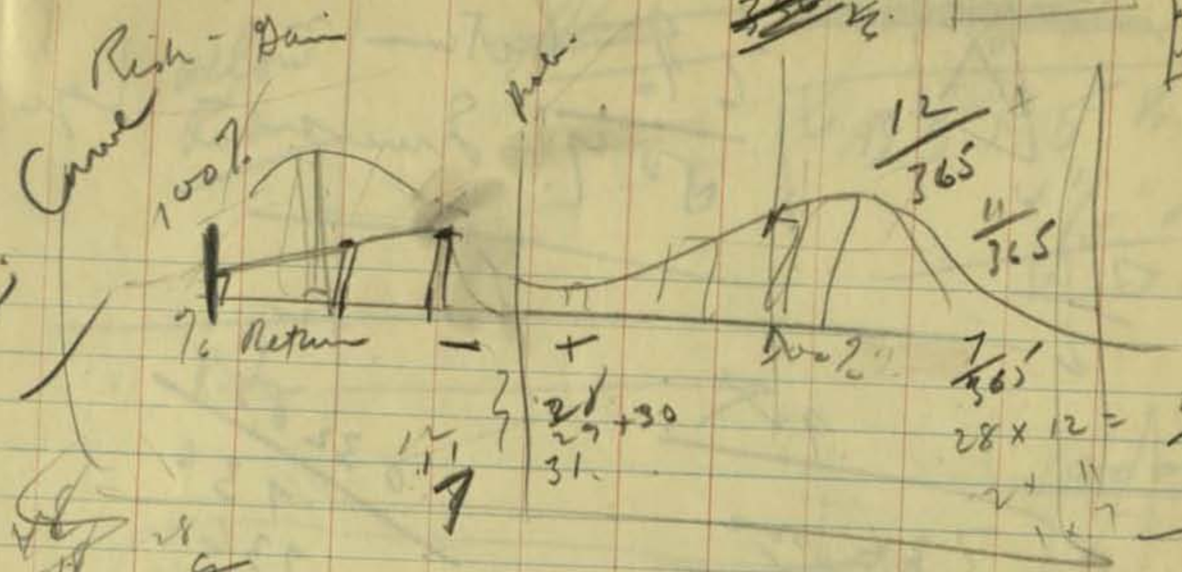
.02 - 6 mos
.05 1 yr
.10 18 mos
.25 2 yrs

Deterioration danger
Savings available
by mass Buying -
Price reduced from
$110 to $100


-100%
2½%
+100%
X

Worth of
Risk:
Gain Curve

Risk - Gain



$\boxed{365}$

$28 \times 12 = 336$

336
22
7
365

3 - 1 won't fund

$\frac{10}{10}$ 5 yrs
100%
loan
$\frac{1}{2}$ 6 mos s.
250/500

$\frac{9}{10}$ 2 yrs
50/100

$$\sum_{r=-\infty}^{r=0} P(r) = .75$$

$$\sum_{r=0}^{+\infty} p(r) = .25$$

$$p(.25) = .5 \sum_{-\infty}^{0} p(r)$$

$$p(.5) = .4 \sum_{-\infty}^{0} p(r)$$

$$p(1.0) = .1 \sum_{-\infty}^{0} (r)$$

$\boxed{365}$

$$\sum_{n=1}^{n=28} p(n) = \frac{12}{365}$$

$$\sum_{n=29}^{30} p(n) = \frac{11}{365}$$

$$n=31\ p(n) \quad \frac{2}{365}$$

16

12

① ~~$\frac{1}{28}$~~ +

$$\frac{336}{365} \cdot \frac{12}{365}$$

$$+ \frac{22}{365} \cdot \frac{11}{365}$$

$$+ \frac{7}{365} \cdot \frac{7}{365} =$$

21/27

6% Return on 2m
50%. Increase in Size of Bus.

7%

p(≤0%) ≥50%.

p(≤-10%) = 0

p(≤0) ≤10%

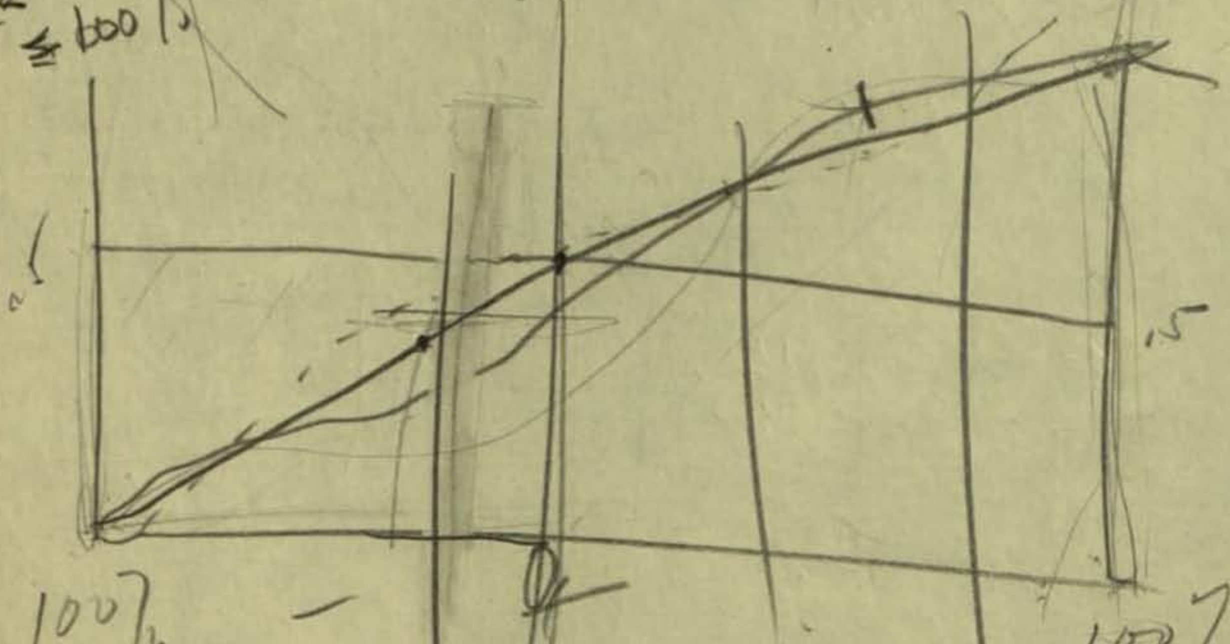
p(≤50%) ≤100%

.92
365) 336.000
328 5
7 50
3288

365
12.000
10 95
1 050
730
3 200
2920
2800

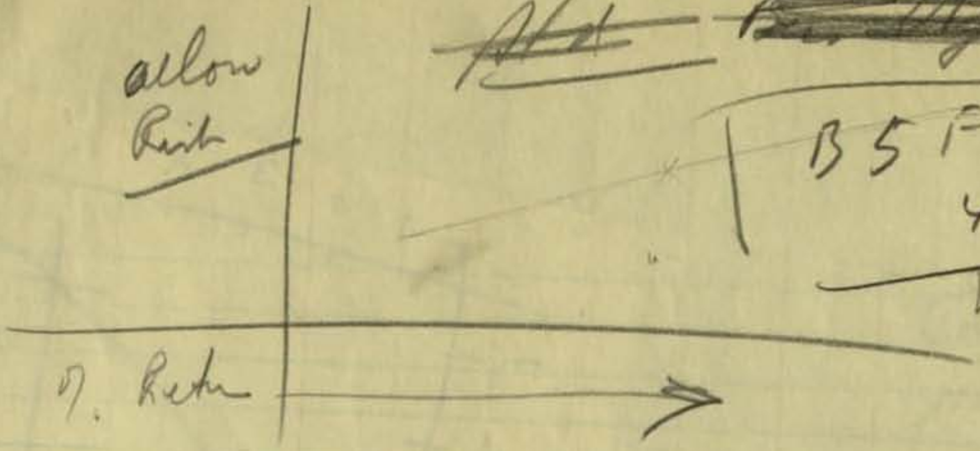
.92
.03288
736
736
184
276
.0302496

.0302496
16
1.5000000
302496
1975040
19

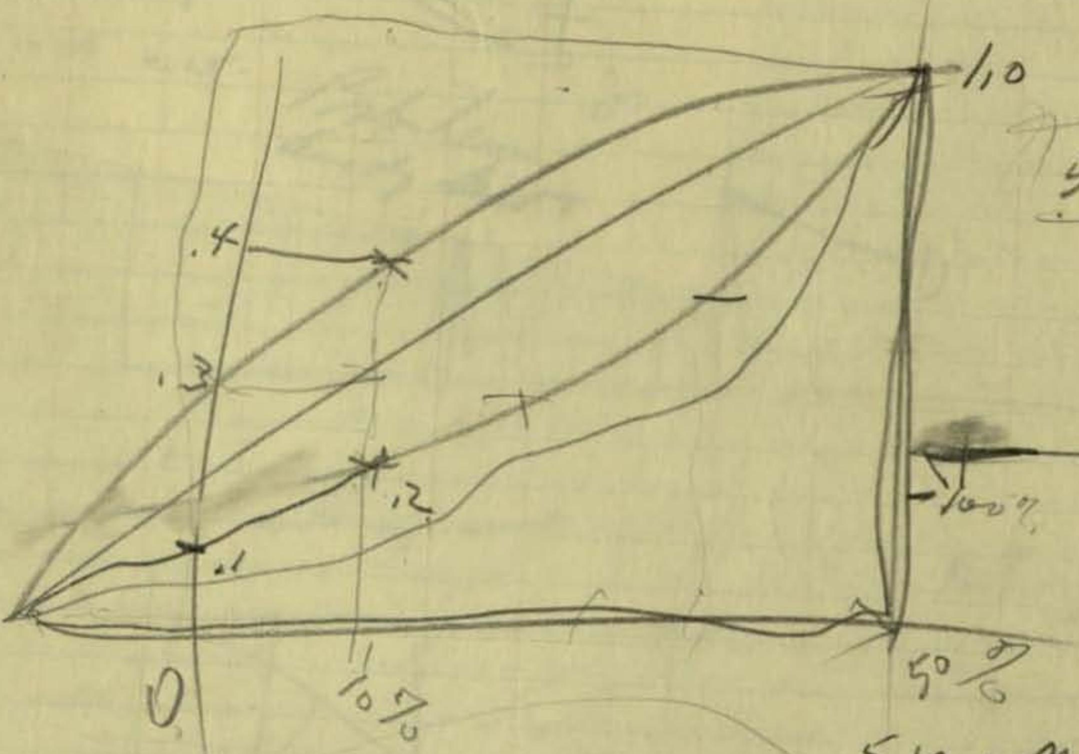


~~[illegible]~~ ~~[illegible]~~

B5F-5-B
4¼" dia
trial lengths

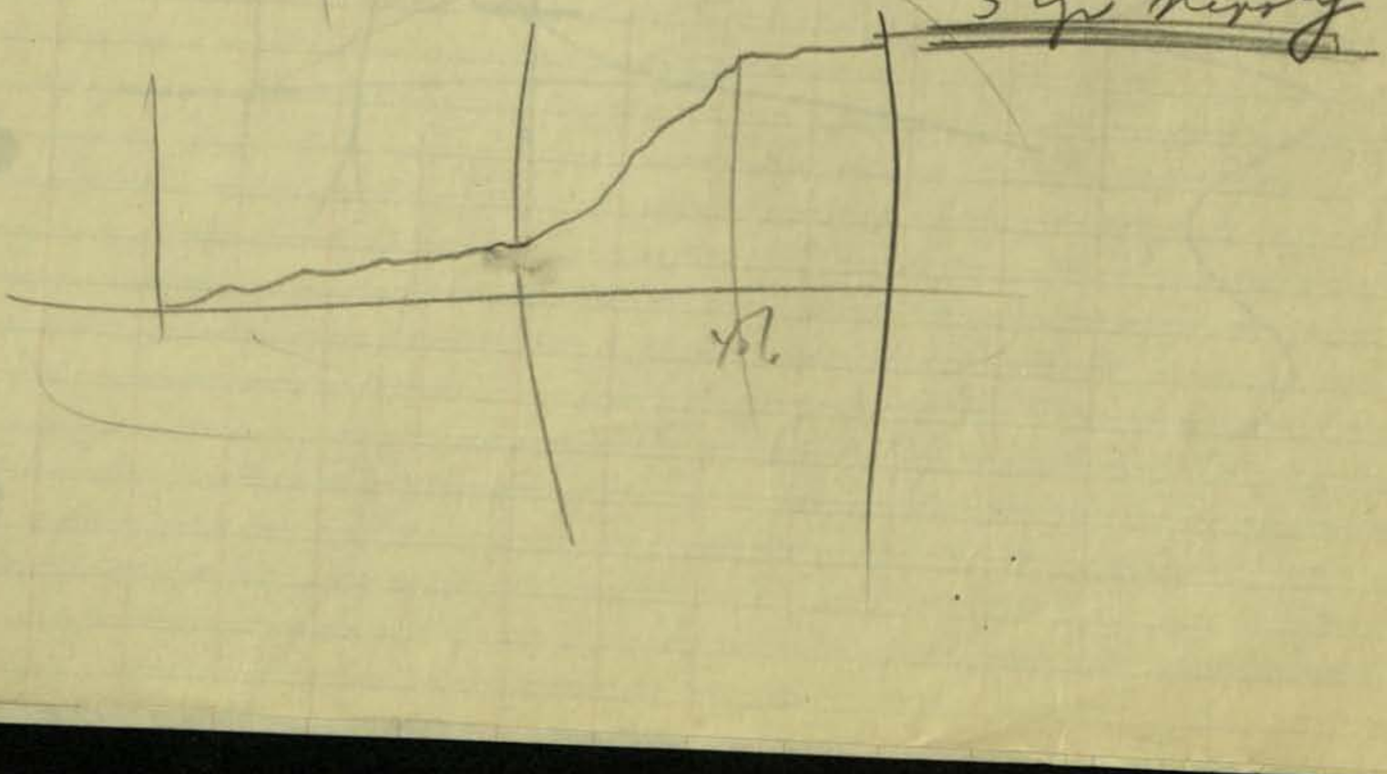


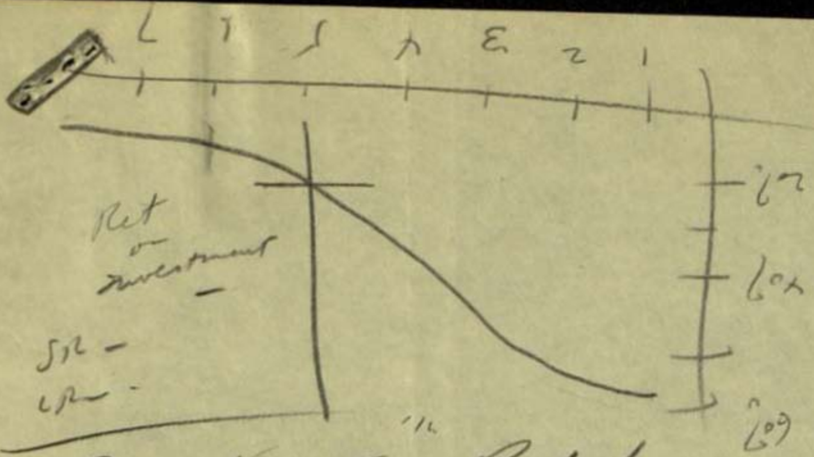
100000#
sq



5000
Production

return on inv

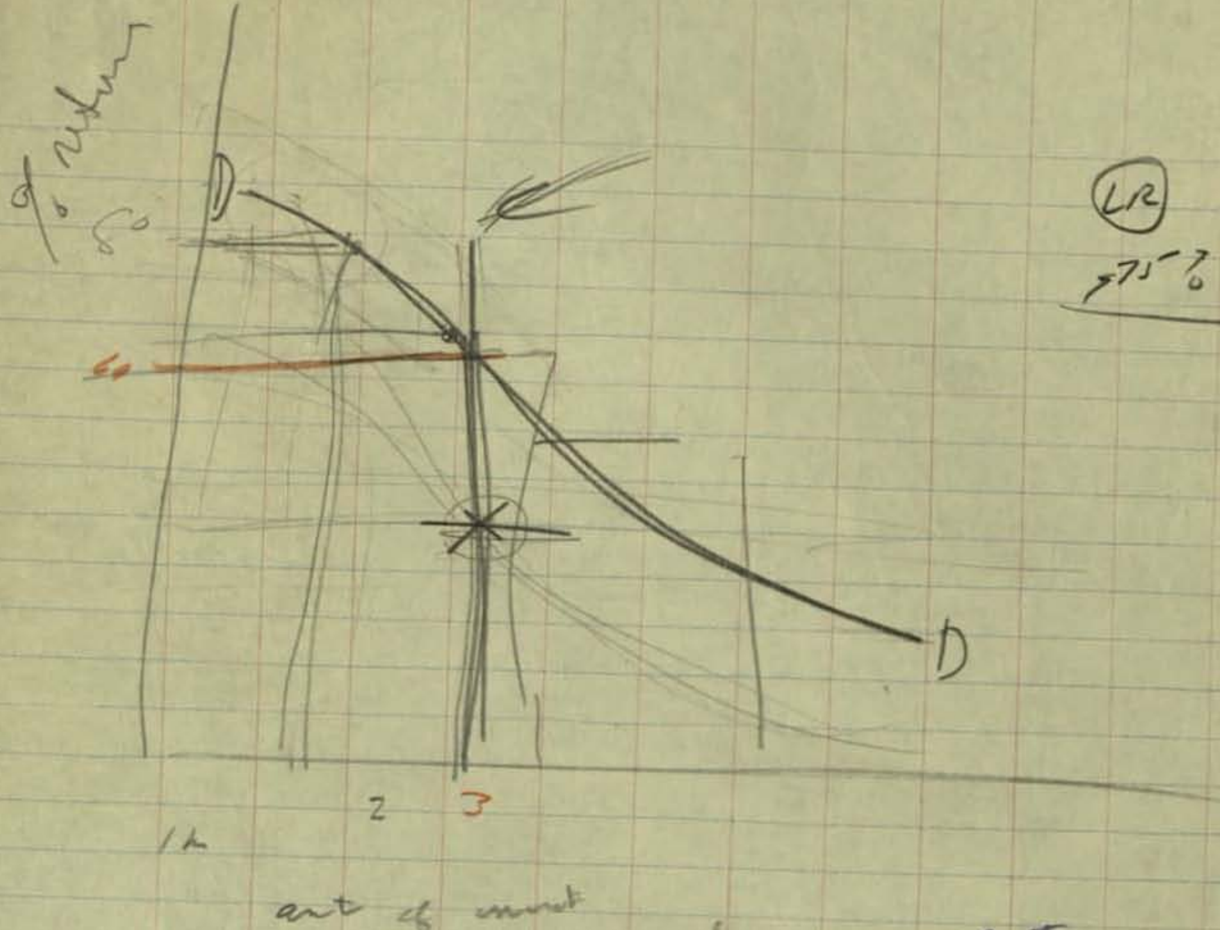




Commod mkt -

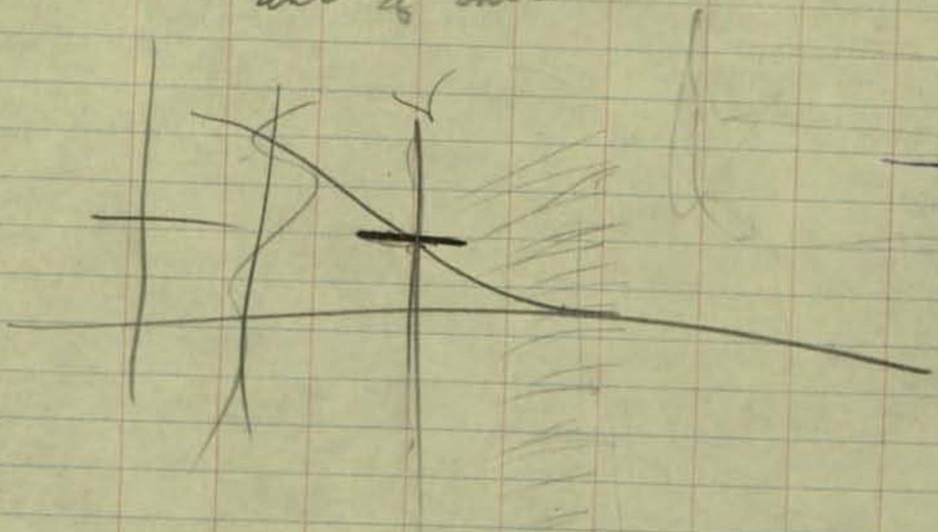
Bob Leaven
Accty Dept

1/30

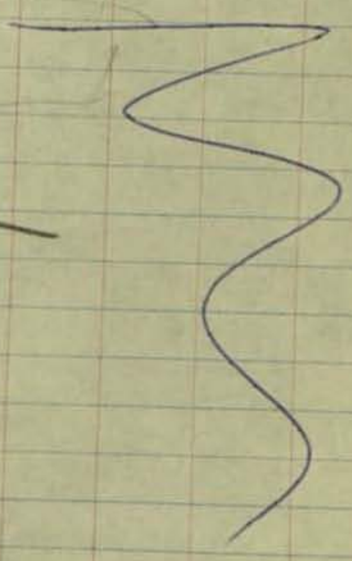


LR

>75%



Action on Investment Cycle —



Get Cost Reductions for Inventory Reductions

Discuss with Ford -

see Bill Ramer for Accty Inst.

1. Cycle Reduction - [illegible]
2. Purch of less expensive mate
3. EOQ should be penalized for minimum inventory
4. Lowered mfg costs.
5. Reduction in planned stock of [finished / in process / raw
6. Disposal of Obsolete
7. Design standardization + catalog [illegible]

8. Level of stocking /
- use of collation charts.

---

a) Incentive
b) fairness

Cost of Carrying
Ret on Inv
Obs + Del
Possession

} 25% approx

FN-32-A (3-52) rev.

Mail To Burt Grod

Division Mfg Svcs

Location 36/122

FOR ATTENTION FOR APPROVAL

RETURN WITH COMMENTS

REPLY sending me copy

NOTE and Return

✓ PER TELEPHONE conv. of today

NOTE and

From J Thurlow

Division

Location 5/549

Telephone No. Date

GENERAL ELECTRIC

SUBJECT

COPIES:

Schenectady, October 28, 1953

Managers-Finance

Gentlemen:

Enclosed for your review are several copies of a draft of a proposed revised General Accounting Instruction on Cost Reductions.

This revision has been prepared by J. W. Thurlow of Cost Accounting Services after survey of the cost reduction practices in several Departments and consultation with a number of you and your cost people. The purpose has been to amplify the Instruction in certain respects and to make a clearer distinction in others in an attempt to reconcile the primary factor of supervisory incentive with the supplemental objectives of integrity and consistency in the reports. Since portions of the approach represent basic modifications, we would greatly appreciate receiving your frank opinions and suggestions.

We shall appreciate it if you would let us have your comments by November 28, 1953.

Very truly yours,

G. W. MARSH

GWM:ad
Enclosures

Keys 1,2 and 3
Group Executives
Division and Department
  General Managers

D R A F T

GENERAL ACCOUNTING INSTRUCTIONS

(For Use of G-E Employees only)

COST AND EXPENSE REDUCTIONS

TAB No. 301

I. GENERAL

The purpose of this Instruction is to outline a standard basis for measuring specifically the effectiveness of <u>certain</u> cost reduction efforts.

In order to facilitate the prompt measurement of actual accomplishments against cost reduction objectives and budgets, it is customary (1) to compute cost reduction results in terms of budgeted rather than actual output and (2) to report in the current period the estimated savings for a full year rather than only for the remaining months of the current year. For these reasons, the aggregate amount of the specific cost reductions reported in any one year will not be fully reflected in operating results for that year. Rather the profit and loss statement of a Department for the current period will reflect the results of only a portion of the cost reductions reported in the current year plus the results of reductions reported in prior years. This discrepancy between the period in which cost reductions are reported and the periods in which they are included in operating results should not, however, affect the basis of computation of cost reductions. The amount of each cost reduction should represent the saving in cost or expense which will be reflected in the Company's income from sales (although not necessarily in the current year) provided actual output is equivalent to budgeted output.

why use annual years

II. DEFINITION

Cost reductions may be defined as the lowering of the accepted standards of cost of either a product or a specific element of cost not directly related to a product. A cost reduction should result from a specific project, program or individual effort for the purpose of reducing costs by means of simplification of design; improvement or elimination of a method or procedure; conservation of materials and supplies, or substitution of less costly materials, supplies, or services; purchasing negotiations affecting previously established sources, prices and terms of purchase; or any combination of these.

any others?

While it is recognized that cost reductions do occur as a result of changes in investment, because of the relatively high proportion of intangible factors entering into the evaluation of such cost reductions, they should not be included in cost reduction budgets. Likewise, the reporting of such cost reductions should be confined to a memorandum basis.

?

In the foregoing definition, the term cost includes not only direct material and direct labor but also specific elements of indirect manufacturing expense, product engineering costs and expenses, distribution expense and administrative expense.

III. EVALUATION

Reported savings should represent only actual validated instances of the decrease in or avoidance of expenditure. The following considerations should be taken into account in evaluating savings for various cost elements:

1. Direct material

Reports of direct material savings should represent reductions in usage or usage at less cost accomplished through the efforts of the Department as a result of planning or design changes or negotiated reductions in established prices. Savings reported from the substitution of a purchased item for an item manufactured in the reporting Department or the reverse should ordinarily be evaluated by comparing the vendor's delivered selling price with the normal shop cost of the item.

or should it be mc

Market fluctuations, voluntary price cuts and corrections of errors on invoices should not be included as cost reductions.

how about catching errors in orig orders.

2. Direct labor

Reports of direct labor savings should be confined to reductions in the cost of direct labor resulting from changes in planned labor operations or reduced piecework prices as the result of product redesign or replanning the job. Savings resulting from a change from established daywork to incentive may be included as a cost reduction.

3. Spoilage and extra costs

Spoilage and extra costs savings should be considered cost reductions only when the project resulted in a change directed specifically at reducing spoilage losses and extra costs, and only when the saving can be definitely attributed to the change rather than a general improvement in efficiency. Elimination of rework due to defective tools which are correctable through normal maintenance operations should not be included as a cost reduction.

4. Indirect manufacturing, product engineering and commercial and administrative expenses

Savings should be limited to specific reductions in (1) expense labor which is actually removed from the payroll or transferred without replacement to an activity representing an additional volume of work or (2) expense materials. Savings in total indirect manufacturing and product engineering expenses that result from a decrease in production volume or savings in unit indirect manufacturing and product engineering expenses that result from an increase in production volume should not be considered cost reductions.

very narrow definition

All cost reductions involving a labor saving should also include provisions for reductions in overhead expense directly related to the labor involved. This does not mean that the normal overhead rate or theoretical overhead factors should be applied to labor reductions but rather the items of overhead expense that are actually eliminated as a result of labor savings, for example, Employee Benefits expense.

what % is this %.

Savings which require the purchase of new machine tools or replacement of an old machine tool should be reduced by one year's depreciation at <u>normal</u> rates (in the case of new tools) or the net annual increase in normal depreciation (in the case of a replacement tool). Full cost of new machine tools and their <u>installation</u> will not be considered in evaluating the saving.

how is this depreciated/

In the redesign of a product or a change in method or material, the savings should be measured in terms of the specific differences in direct material, direct labor, and those manufacturing expenses which are affected by the change. These savings should be adjusted by the deduction of one year's amortization of the engineering and tool expenditures which were necessary to create and put into effect the change in manufacture. Expenditures for new dies, jigs, fixtures, templates, etc. should, for this purpose only, be considered as amortizable over the expected useful life of the tools.

5. <u>Transportation</u>

Savings in incoming or outgoing transportation because of change in terms, freight classification, reductions in weight, etc., as the result of cost reduction effort should be reported as cost reduction savings.

6. <u>General</u>

Savings on new products or products redesigned for higher performance standards should not be inflated by the reporting of decreases in starting costs. Only savings which can be realized after the elimination of starting cost difficulties should be considered cost reductions.

Where a cost reduction involves both increase and decrease in cost and the two are obviously related and readily ascertainable, only the net of the increases and decreases should be reported as cost reduction savings. Changes of a temporary nature only should not be reported as cost reductions.

IV. COMPUTATIONS

Cost reductions should be reported at such time as the proposed changes are incorporated into the regular operating routine and should be computed on an annual rate basis as follows:

1. Products included in original budgeted manufacturing load:

   Annual rate based upon the original budgeted production rate for the current year.

2. Products not detailed or included in original budgeted manufacturing load:

   Annual rate based upon the anticipated annual production rate at a normal production level.

3. Special equipment or design that will be discontinued during the year:

   Base computation on the specific order or the quantity still to be manufactured.

V. REPORTS

A report of cost reductions, evaluated and computed in accordance with this Instruction, should be submitted monthly to the Manager-General Accounting Services Department on a form similar to the attached Exhibit A in those cases where accumulation and consolidation of such data has been requested by the responsible Group Executive.

In instances where two or more Departments cooperate in effecting a cost reduction, they should mutually agree upon the portion of the reduction to be reported by each.

In certain cases cost reductions originated by one Department have application in other closely allied Departments and are adopted by the two or more Departments at about the same time. In these instances the Department originating the cost reduction should report (1) the portion applicable to its own operations as a regular cost reduction and (2) the amount of saving realized by the other Departments on a memorandum basis as recognition to those responsible for the work. The other Departments which have benefited from the idea may report the portion applicable to their operations provided the origin of the reduction is clearly indicated by footnote.

VI BUDGETS

A budget of anticipated cost reductions may be requested each year showing information similar to that on the attached Exhibit A.

It is essential that the budgeted amount and the budgeted percent of output be established on the same basis as will be used in reporting actual results so that a correct measure of accomplishment in relation to budget is subsequently shown.

____________________Department

COST REDUCTION REPORT

Period ending __________________

	Current Month at an Annual Rate	Year to Date at an Annual Rate					Annual Budget
		Actual		Budget			
	Amount	Amount	% of Annual Budgeted Output-a)	Amount	% of Annual Budgeted Output -a)	R%	% of Output-a)
Savings affecting own operations							
Direct Material							
Direct Labor							
Expenses:							
Manufacturing							
Engineering							
Transportation							
Commercial and Administrative							
Total							

As a memorandum:
Savings effected for other Departments-b)

(a- Annual budgeted output at manufacturing cost
(b- Show details by Department and type of reduction

EXHIBIT A

Bob ELLSWORTH -

1) Define + describe determination of ABC class

2) T/O objectives, range or philosophy

A) ordering
Timing
Prod levels

B)

C)

3) Econ Qty + Time

4) Obsolete + Surplus

Performing an ABC analysis for
Inventory Control Purposes

1) determine level of analyses - fin pts
~~[illegible]~~ + pts for ~~[illegible]~~ + [illegible]
raw for [illegible]
Subassys.

~~2)~~ Matl only
Labor only
Stock only
etc

2) aggregate in some intelligent
manner -
Part name
Prod. Line
Type of matl or mdse reqd
Source of [illegible]
Product type

3) Get usage + cost data on ea item

4) Calc yrly value

5) arrange in descending sequence

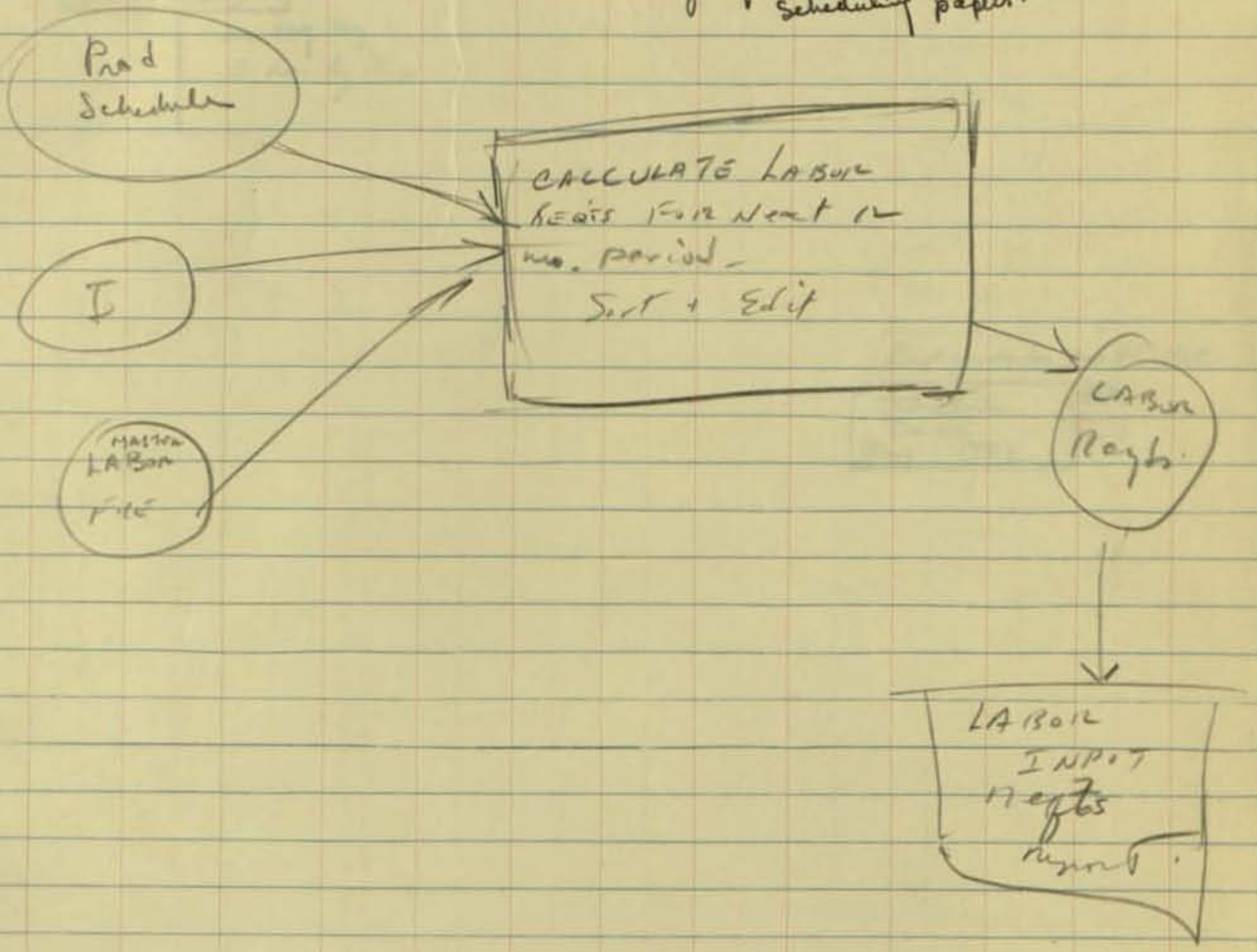
6) Summarize total $ ea 1%

7) plot results % of value vs % of parts

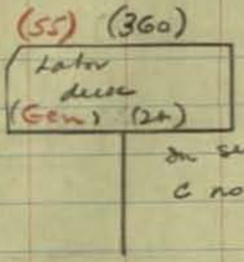
8) make 'neat' pts

LABOR INPUT Determination

Zurflieh discussion -
Scheduling papers.

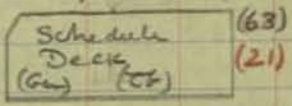


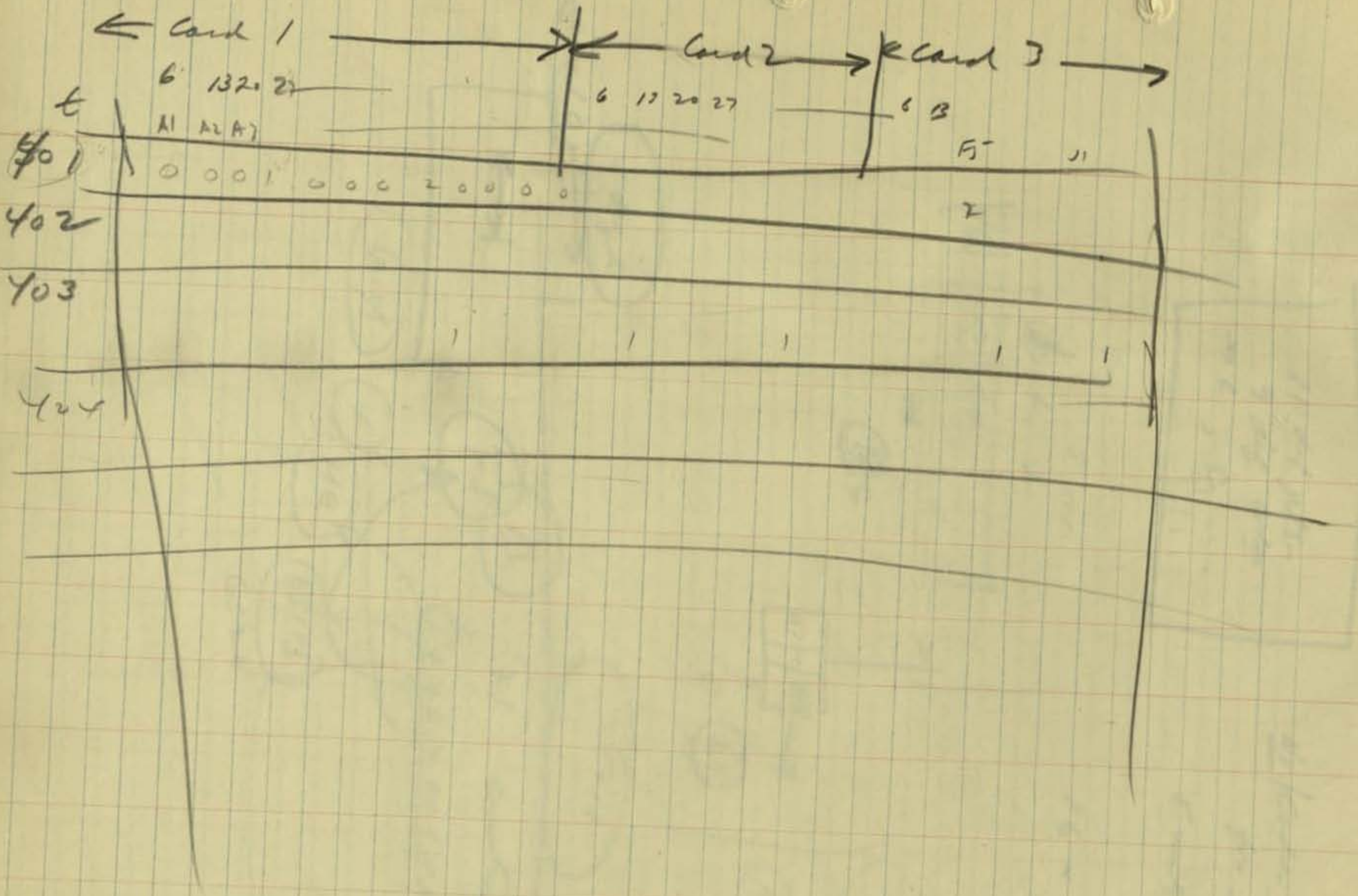
Labor Input determination



In seq. by C no. by item

Prepared for mat'l det.

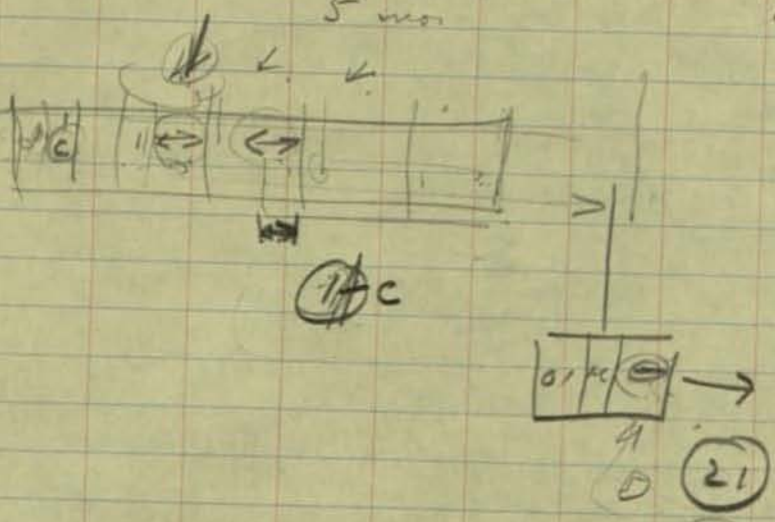




,26
32
2 5 2
2 7 8
1032

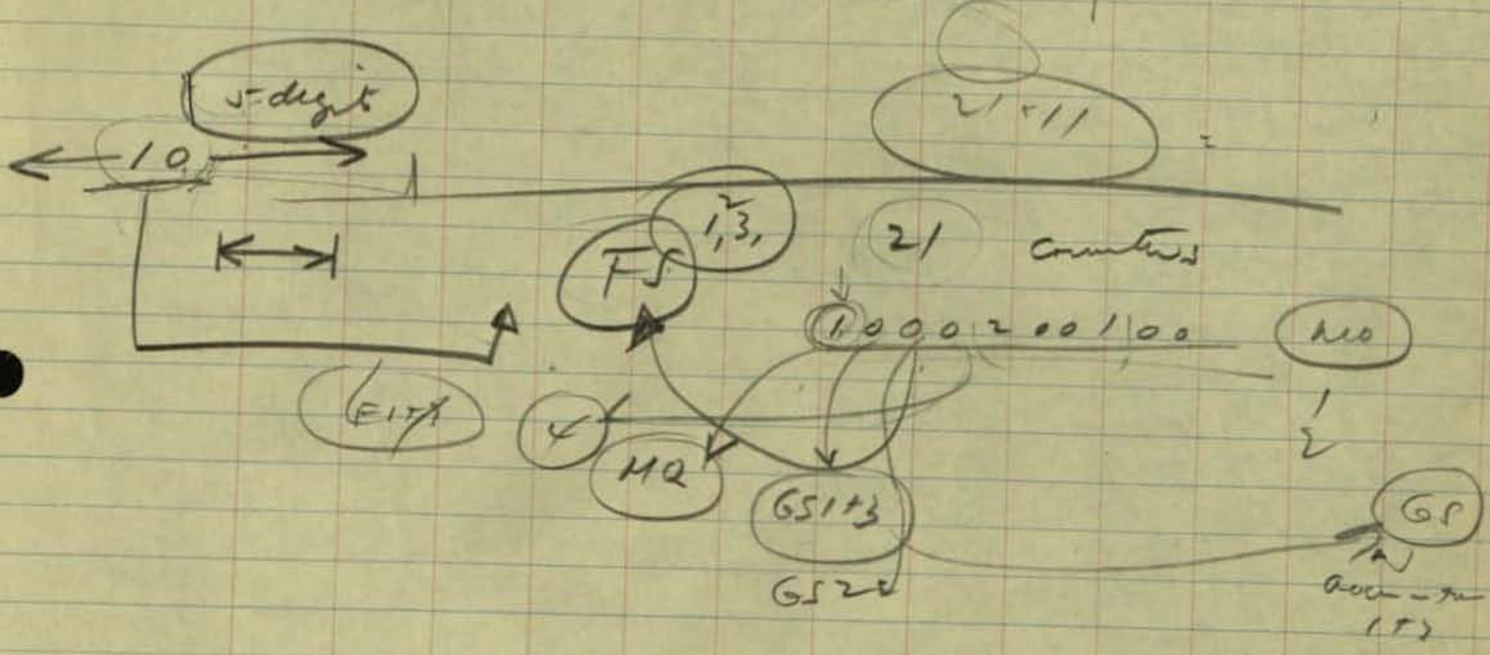
11 dif pts—
9 dif codes.
→ L , C.....

No./Code
for ea of next 21
5 units/no.



16 × 10 = 160
3
480 digit

9 × 21 =
185
no



92¼
/2¼
87

Master from Engrg Typing
reproduce in [illegible] all sets – [illegible] –
? mast 3 cost copy; 2 8½ × 8½ copies
Crombie puts Section on ea master
To prod section — filed in prod unit
On Call – pull 1 master
1 cc
put S.O., Req
no / unit
date
qu
} both copies
fill in qty, routing on master – Source dept.
(Cost calc qty on own copy)
Sup straight 8½ × 11 copies
after down to 2 send in 8½×8½
master or identical set except only 1 8½ × 8½

209.

2
2
2
3
2
2
1
1
1
1
1
1

Tb 19 → Gen 11 = 30 items

Matl

12 - Gen
20 - Tb

3×20 = 60
1×12

+ Gen C item
Tb C item

32 items

32 × 25 = 800 Cards max
500 = actual

Tb 25
Gen 10
35
+ Extras 2
37

Labor.

Gen - 11
Tb - 26

9 Gen Codes

---

max Cycle = 9 mos.

25 × 37 × 9 = 8325 max
4500 act

Prod Sched.

21 months

Ship Jan (Cots)

pick out all matl cards for codes thru that d=1

labor card c=1

Feb d=1+2
c=1+2

Sept full yr:
d=9
c=9

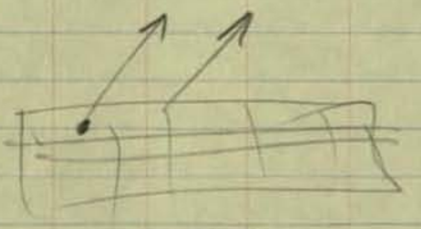
GP qty of ea code for ea mon ea card + month itself

32 × 100 = $\boxed{3200}$

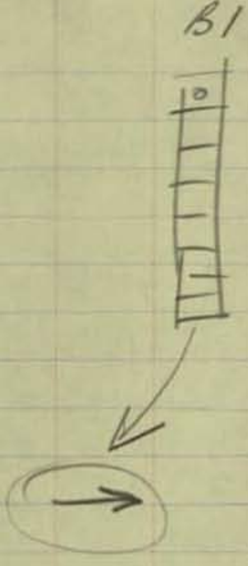
②

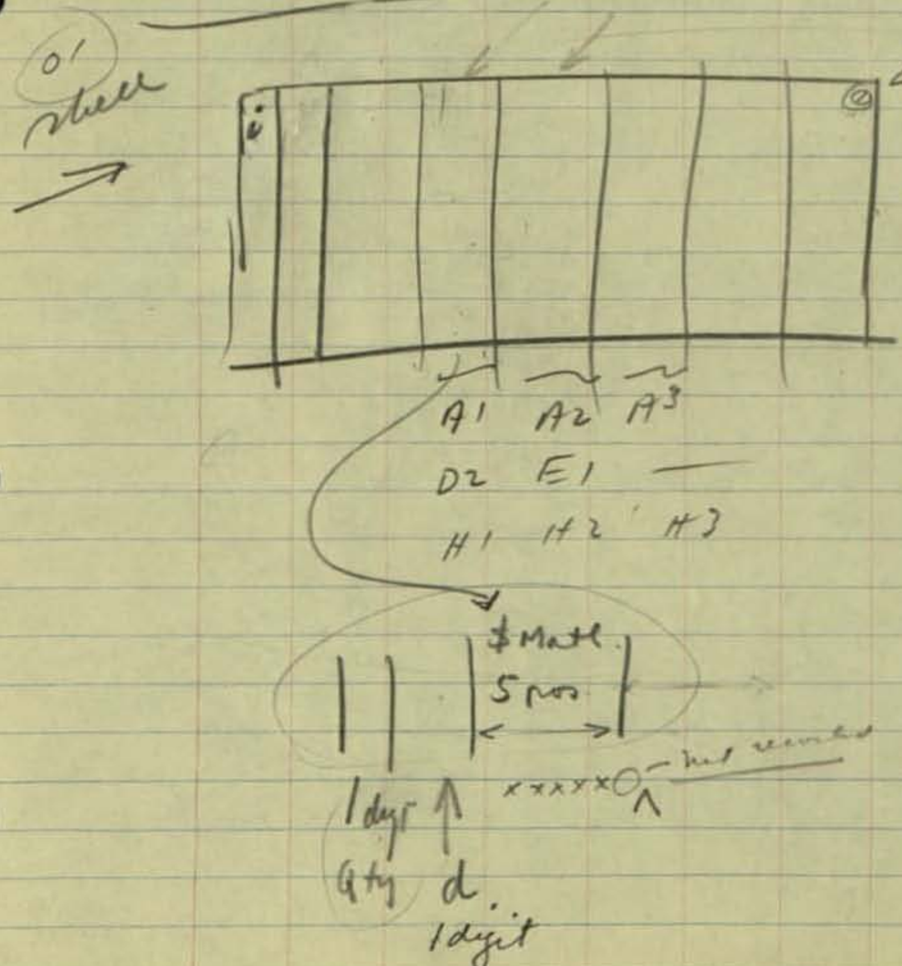
$\square \leftarrow Q_j^t$

$25 \times 21 = \boxed{525}$



t-c





0
①
2

$32 \times 3 = 96$ cards

3 cards/item/mo

21 months

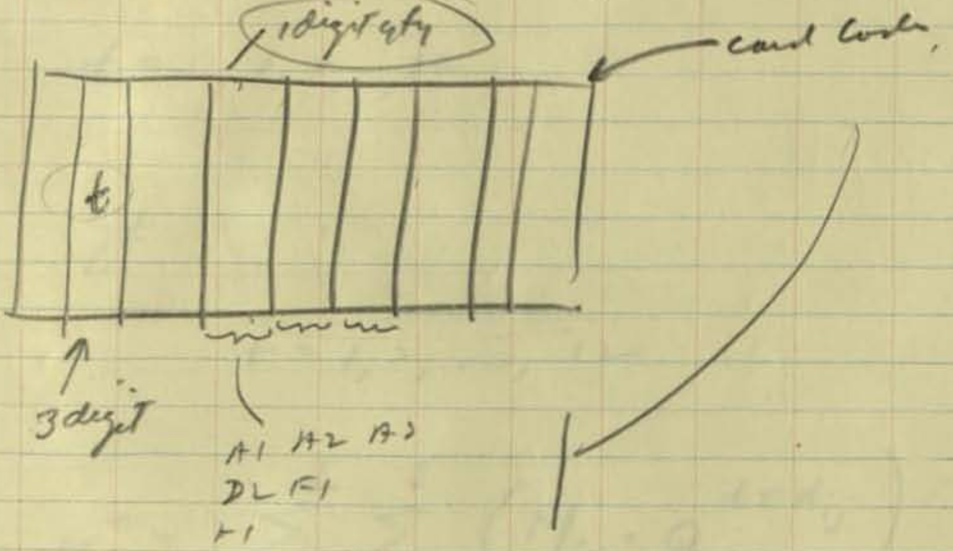
63 cards/item

× 32 items

126
189

2016

KP master Sched cards for ea mo.



21 × 3 = 63 cards to represent entire prod sched.

M^t

$t = 1, 2, \ldots, 12$

L^t

$t = 1, 2, \ldots, 12$

$$M^t = \sum_{i=1}^{I} \sum_{j=1}^{J} \left(M_{ij} \cdot Q_j^{t+d_{ij}} \right)$$

$J = 25$

$I = 32$

$$L^t = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{c=1}^{C} \left(L_{ij}^{c} \cdot Q_j^{t+c} \right)$$

$C = 9$

$J = 25$

$I = 37$

-515 (3-52)

TREASURER'S OFFICE
GENERAL ELECTRIC
COMPANY
1 River Road, Schenectady 5, N. Y.

Tell Contract
to put on
[illegible]

UNITED STATES SAVINGS BOND

This Bond is of value only to registered owner.

Finder Please Return to Owner or to General Electric Company

STRICTLY PRIVATE

KEEP IN A SAFE PLACE

The enclosed United States Savings Bond was issued against the accumulated deductions in your installment account at the end of the month and year shown in the upper right-hand corner of the bond.

This bond should be carefully examined, and any discrepancies in amount, denomination or inscription should be immediately reported to your payroll division. Changes in address on Series E bonds already issued need not be made.

Do not cash this Bond except in a real emergency. The longer you hold it, the better it gets.

Production Schedule gives
Q_j^t for ea month into future
Material cost study gives
M_{ij} for every item for every code
Labor cost study gives
L_{ij}^d for every item for every code
for $0 < d < D$
where D = max lead time

$$M_i^t = \sum_{j=1}^{J} \left(M_{ij} \cdot Q_j^{t+d_{ij}} \right)$$

$$M^t = \sum_{d=0} \sum_{i=1}^{I} \sum_{j=1}^{J} \left(M_{ij}^d \cdot Q_j^{t+d} \right)$$

$$L_i^t = \sum_{d=1}^{D} \sum_{j=1}^{J} \left(L_{ij}^d \cdot Q_j^{t+d} \right)$$

$$L^t = \sum_{i=1}^{I} \sum_{d=1}^{D} \sum_{j=1}^{J} \left(L_{ij}^d \cdot Q_j^{t+d} \right)$$

Q_j^t } - Existence or non existence in a cert ai key column —
Each col to have time + code significance. The key to be indicated by the prior punching

---

If make 1 card for 1 mo
Need 24 cards at max.

20 codes or so $\overset{0}{\underset{2}{i}}$
480 digits of memory selection

M_{ij} } - 5 digits for money
d_{ij} } - 2 digit for month code

---

must ident j + i / again we could assign blocks of a card to a code. 1 — + 1 item to a card — or use only ~~items with~~ = d_{ij} on a ~~given card~~.

~~Suppose d_{ij} in 1st 2 col of a card is for a given i then~~

~~Composite card~~
~~Free given item~~
Assign num code 1-80 for ea code use letter-num here again

Correspond to col on Q card

Assign item code -
2 digit num.

Master Cards
1-2 Item Code - entire card (i)
3-4 Model code - (j)
5-6 month code (d)
7-11 cost M_{ij}
12 - [Q ty of model j in mo($t+d$)] filled in on time

---

7 models per card
3 cards/item
69 cards

---

entire mult deck

---

max 7 460 cards

Sort M cards by d

$Q_j^0 \cdot [M_{ij}]_{d=0}$

$Q_j^1 \times [M_{ij}]^{d=1}_{d=0}$

$M^0 =$
$Q_j^0 \cdot [M_{ij}]_{d=0}$
$+ Q_j^1 \cdot [M_{ij}]_{d=1}$
$+$
$Q_j^0 \, [M_{ij}]_{d=0}$

Sort Q Cards by d
Collate ; GP
Sort out Q cards

repeat for all d's + t's

M4o Card

Analysis of Material + Labor Input Determinat

Definitions:

M_i = material cost of item i

L_i = Labor Cost of item i

M_{ij} = material cost of item i used in model j

L_{ij} = labor cost of item i used in model j

d_{ij} = ~~time in advance of shipment of model j [illegible] part i by~~ material lead time for part i on model j

L_{ij}^{c} = Labor cost of item i used in model j during ~~time period c~~ the c^{th} period of time before shipment of the model

Q_j^t = Quantity of model j scheduled to be shipped during period t.

The production Schedule specifies Q_j^t for ea time period from $0 \leq t \leq T$.

we ~~must~~ will assume that d, c and t are all in the same units of time, days, weeks, months etc

Tables are available establishing:

M_{ij} and d_{ij} for every i and j

L_{ij}^{c} for every i and j

Therefore -

$$M_i^t = \sum_{j=1}^{J} \left(M_{ij} \cdot Q_j^{t+d_{ij}} \right)$$

where J = the last model no.

Extending this

$$\boxed{M^t = \sum_{i=1}^{I} \sum_{j=1}^{J} \left(M_{ij} \cdot Q_j^{t+d_{ij}} \right)}$$

where I = last item

Similarly for the labor

$$L_i^t = \sum_{j=1}^{J} \sum_{c=0}^{C} \left(L_{ij}^{c} \cdot Q_j^{t+c} \right)$$

where C = max cycle for any part

and therefore

$$\boxed{L^t = \sum_{i=1}^{I} \sum_{c=1}^{c} \sum_{j=1}^{J} \left(L_{ij}^{c} \cdot Q_j^{t+c} \right)}$$

Labor Analysis -

set up 1 Card - i c } constant (t) → 3 digits

i code 2 dig
c code 2 digit
10 Codes/Card

2 card/item/mo
20 card/item
114 = labor Code

ea Code

L^t_{ij} ↔ 5 dig/ ea area

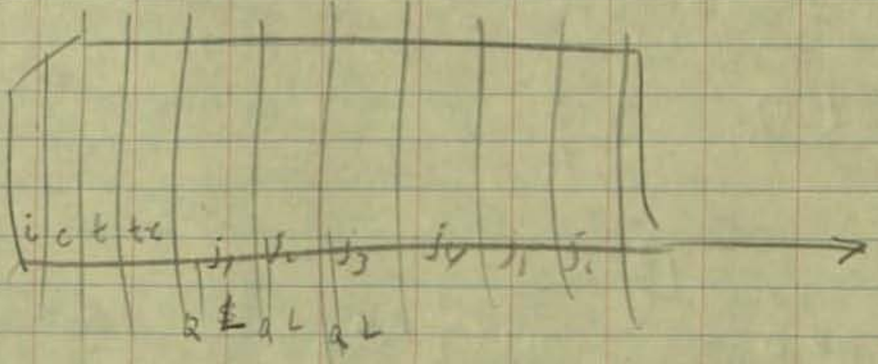
ea area for a Code

4 or | Yes include / No don't include | for a particular (t)

t-c

↔

4 or →



Labor data Card

	i	1-2
	c	3-4
	t	5-7
	$c-c$	8-10
L_{i11}	L_{i1}	11-15
Q_{11}	Q_1	16
		17-20
L_{i12}	L_{i2}	22

10 models

Col 80 - Code 1 Code 0
79 - Code 2

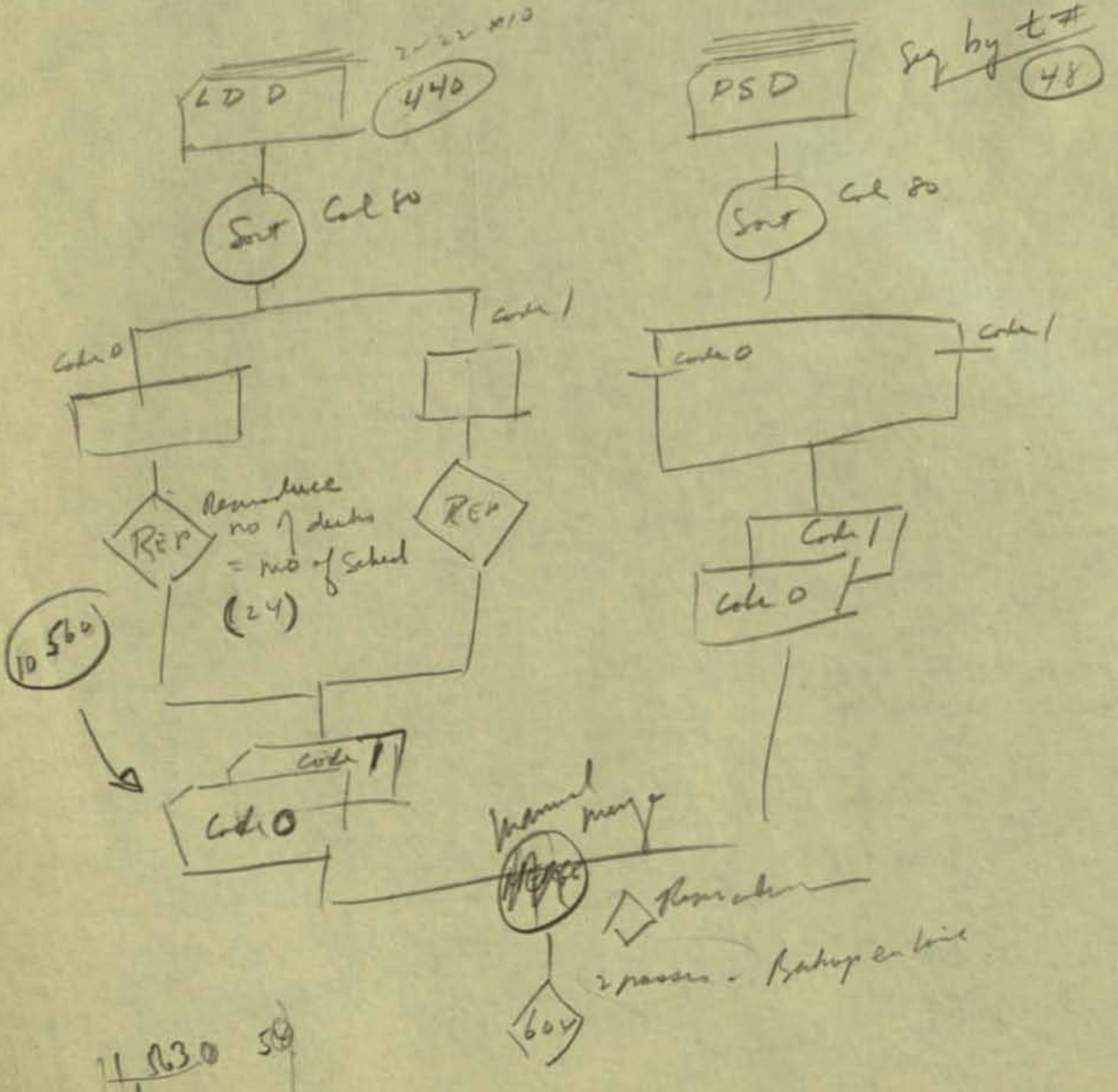
Prod Sched Card

t = 5-7

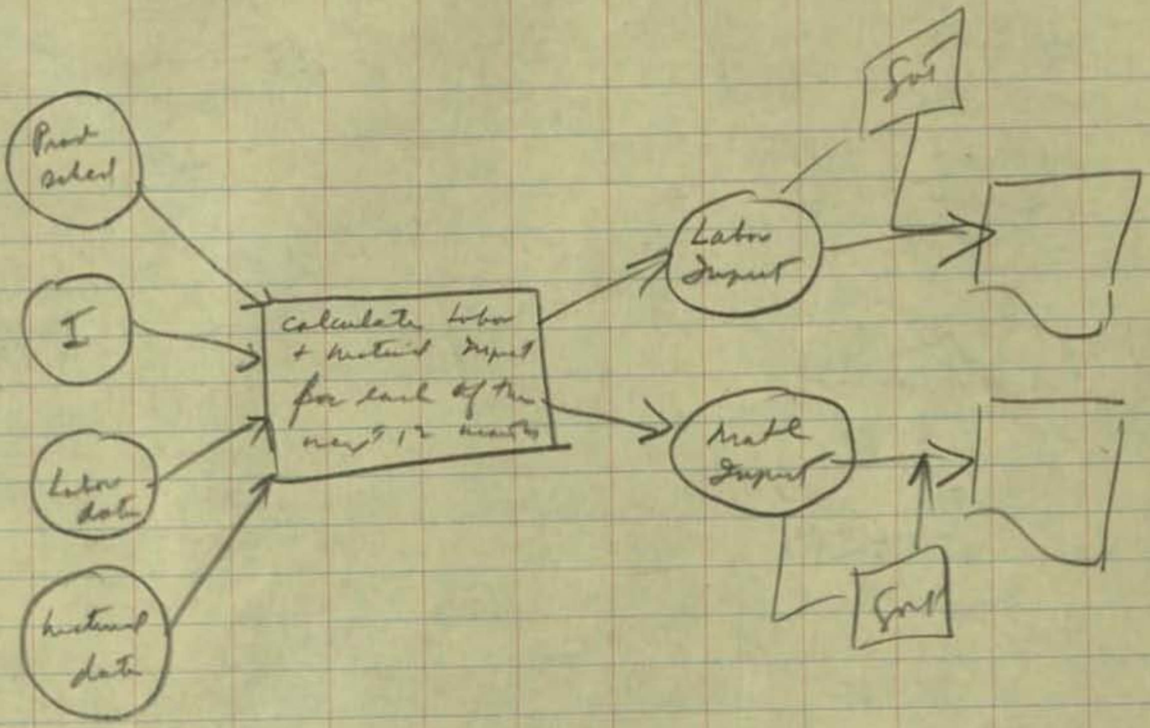
Q_{11}	Q_1	16
Q_{12}	Q_2	22

10 models

Col 80 Code 1 Code 0
Col 79 Code 1



11 1630 59



Prod Sched

000 t

001 | model # | Q_1

002

029 Q_{29}

} 24 Blockettes

Labor data

000 | i | |C|

001 model # L_1

002

029 L_{29}

} 10 Blockettes per item = 220 Bkettes

22 items for file

Material data

000 | i |

001 | model # | d | L_1 |

029 | L_{29}

22 Blockettes

Labor Input

000 | i | t-c |
001 | model # | Q-c |
↓
029

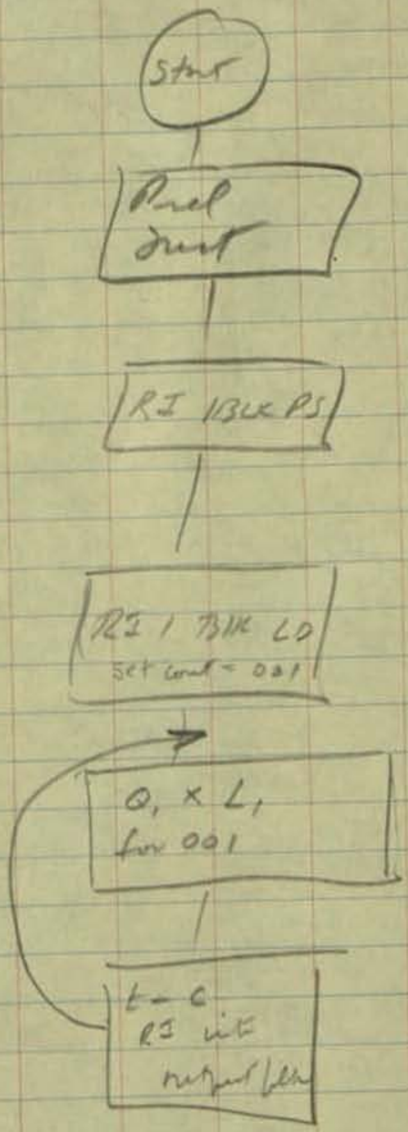
~~1 Blockettes~~ / item

~~item~~ mo
~~240~~ blockettes
5280

Matl Input

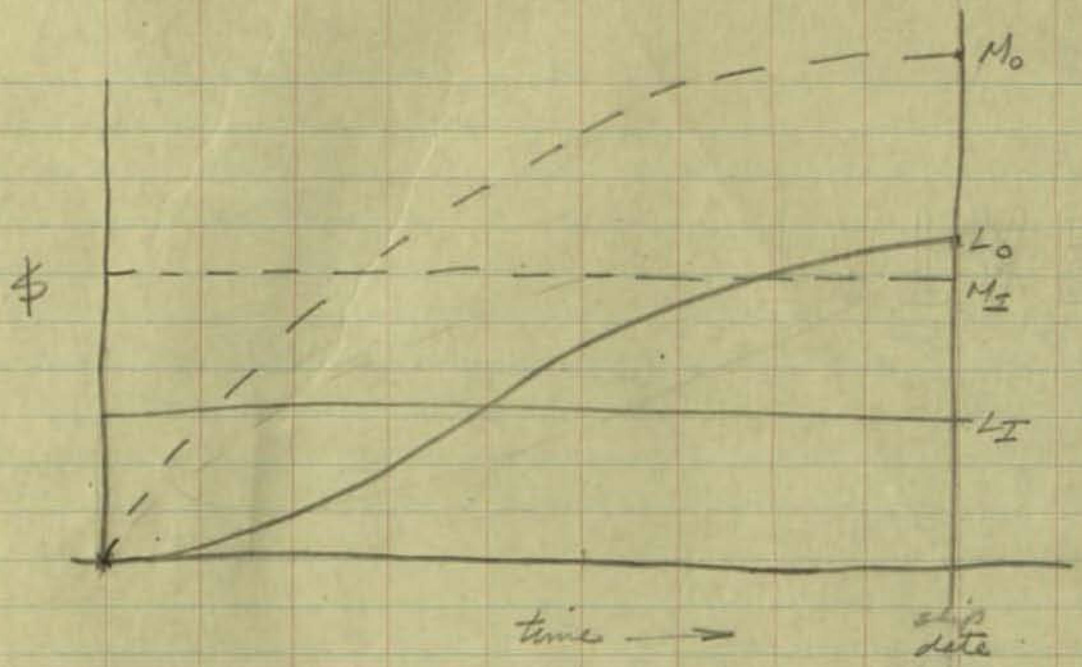
000 (i)
001 model # (t-d) Q-M /
↓
029

528 blockettes


Start
Panel Input
RI 1BLK PS
RI 1 BLK LD
Set count = 001
Q, x L,
for 001
t - c
RI wit
output blk

4/15

(15)



The higher the $\frac{M_0}{L_0}$ ratio the higher the C no.

The higher the $\frac{M_I}{L_I}$ ratio the lower the C no.

The C no. in the normal business will be less than 1, hence the higher the IME rate the higher the C no.

The $\frac{M_0}{L_0}$ ratio is an inherent characteristic of a business & not controllable by managerial efficiency.

The $\frac{M_I}{L_I}$ ratio depends on $\frac{M_0}{L_0}$ and the shape & length(l) of the cycle of manufacture

LM + G 3119

OUTPUT

L - 10.2 % } 11.7

M - 55 % } 63.1 OF MFG. COST

IME - 22 % } 25.2

87.2

INVENTORY

L - 8 %

M - 76 %

IME - 205 % OF 8 %
(16.4 %)

T.O. = 4.5

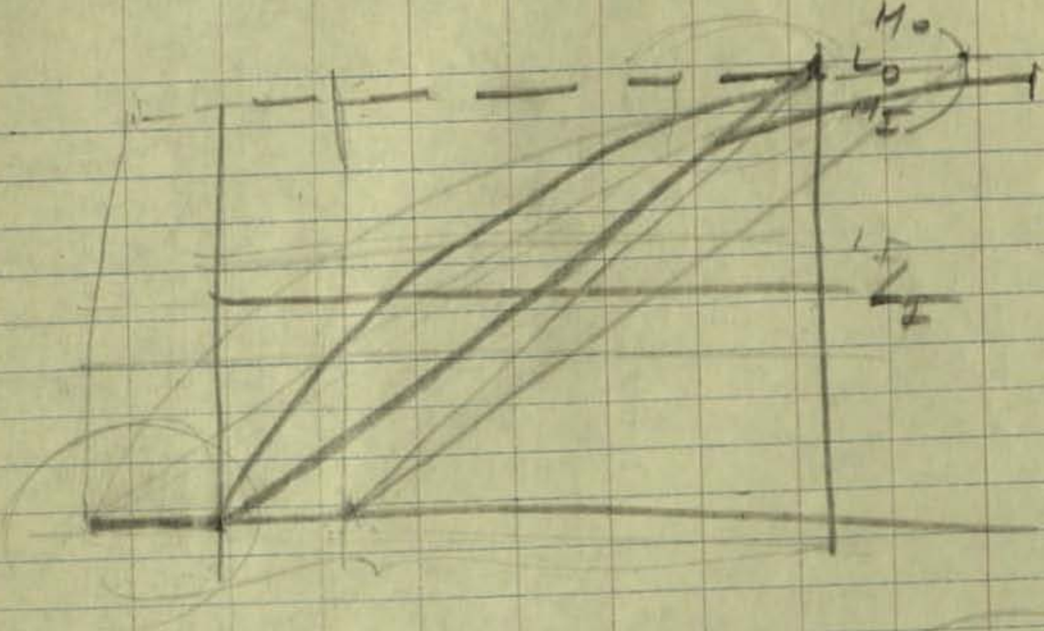
13 WK. MFG. CYCLE

F3 145 3640

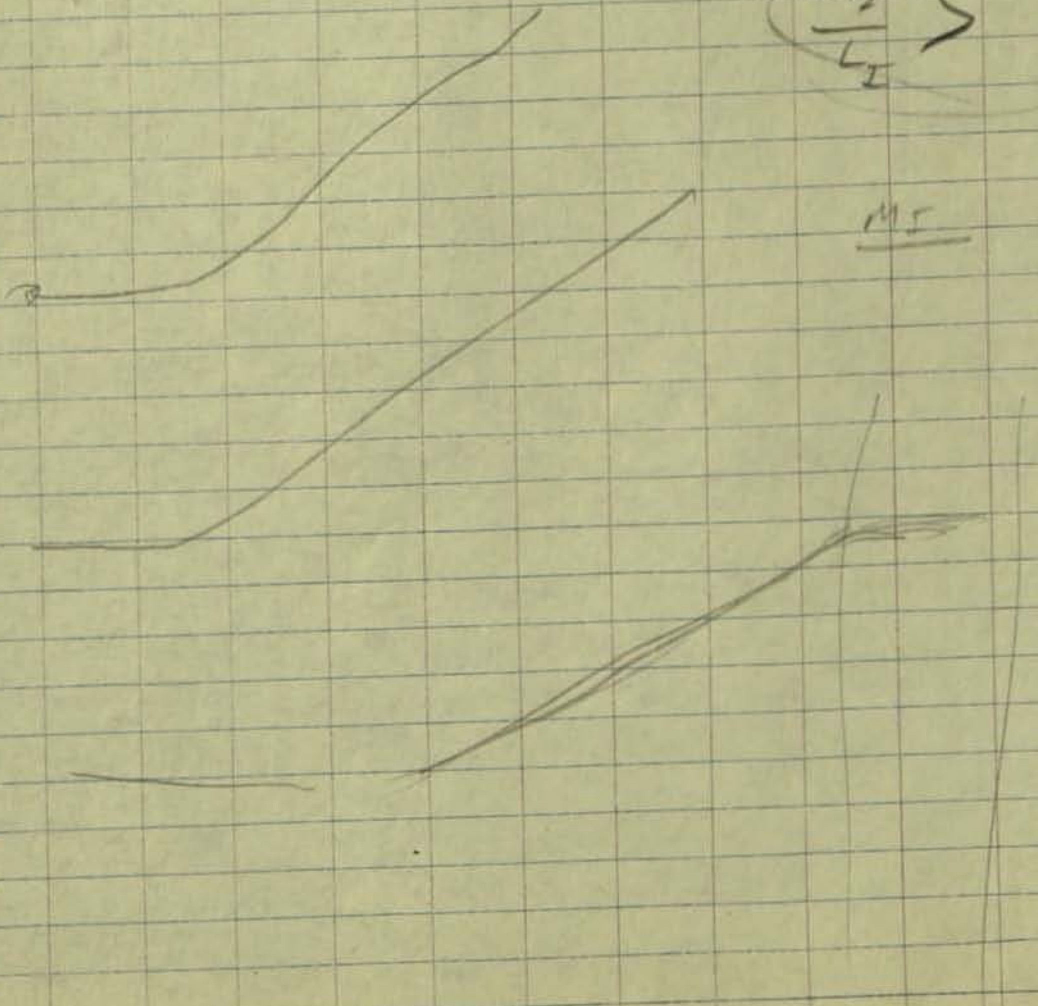
[illegible]

7044E61B
7044E62B

7044E83
7044E84



$\frac{M_I}{L_I} >$



$\underline{M_I}$

$$\text{Act avg Cycle} = \frac{1}{TO}$$

$$\text{Plnd avg Cycle} = \frac{\sum_0^n \text{Cycle for each pt} \times \text{Cost each pt}}{\text{Total cost}}$$

$$\text{Inv} = \text{Cycle} \times \text{Cost/unit} \times \text{no units/yr}$$

$\frac{M_I}{L_I}$ optimum is varying pt for ea

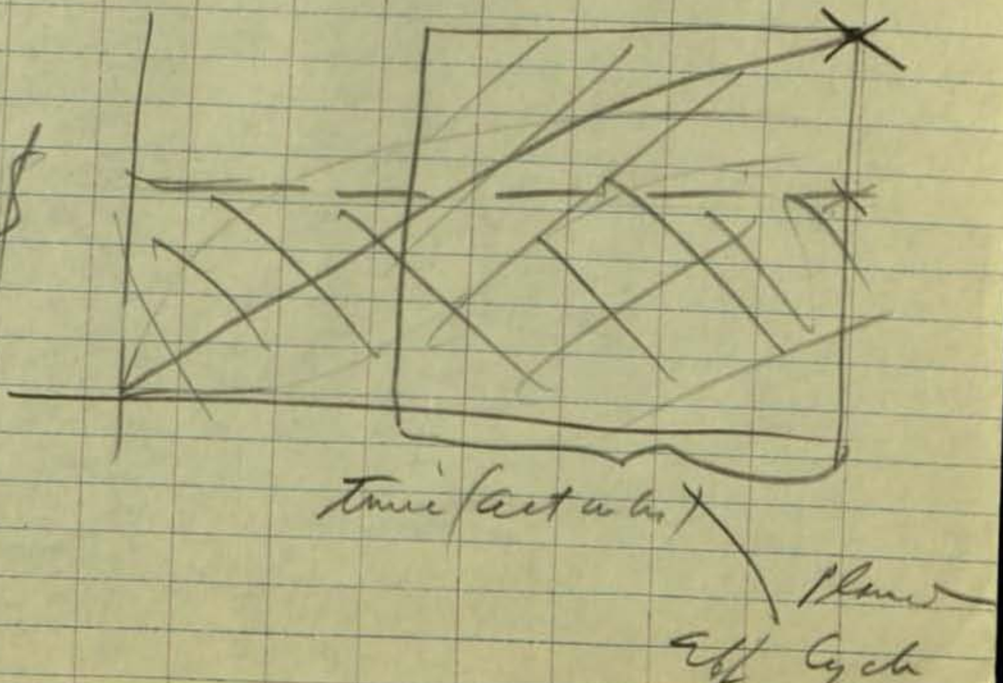
business —

Eff Cycle = $\frac{Inv}{out} \times \sqrt{2}$

$\boxed{\frac{1}{T_0}}$ = $\frac{\text{Effect Cycle}}{\text{avg act Cycle}}$

3 —

$\boxed{\frac{1}{T_0}}$ Planned Cycle



other 40 wks — ~~8~~ 15 — 600

Lend 20 wks — ~~5~~ 15. 300

Ratio 20 wks — ~~8~~ 30 600

60

~~80~~ + 1500

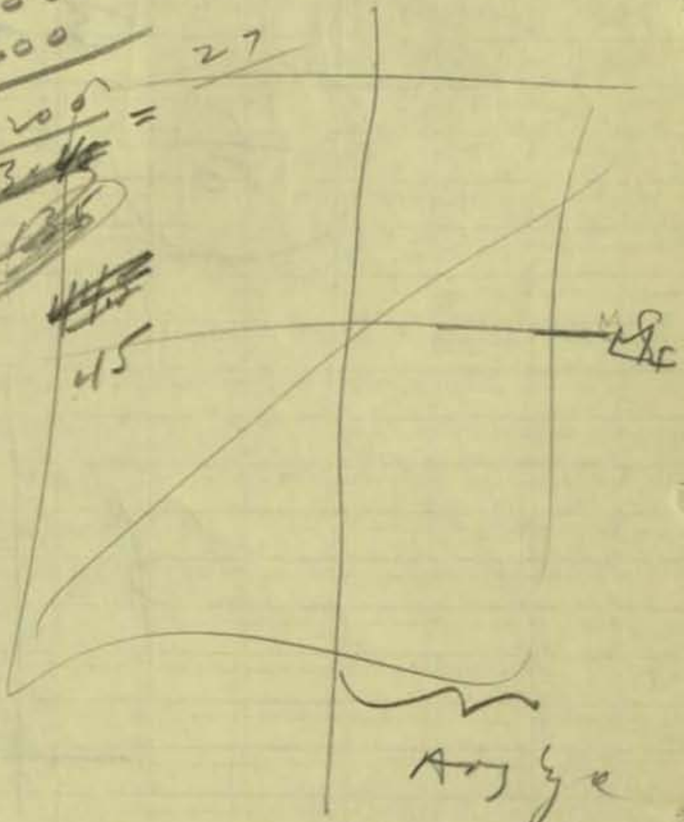
80 / 3 = 27 wks

x 45

1500 / 60 = 25 wks

600
300
300

1200 / ~~3~~ = 45



$$\frac{\Delta TO}{TO_1} = \frac{(Q_2+R_2)(P_1+R_1)-(Q_1+R_1)(P_2+R_2)}{(P_2+R_2)(P_1+R_1)}\frac{L_O}{L_I} \times \frac{(P_1+R_1)}{(Q_1+R_1)}\frac{L_I}{L_O}$$

$$\frac{\Delta TO}{TO_1} = \frac{(Q_2+R_2)(P_1+R_1)}{(P_2+R_2)(Q_1+R_1)} - 1$$

define :

$A = Q + R$

$B = P + R$

$$\frac{\Delta TO}{TO_1} = \frac{A_2\ B_1}{B_2\ A_1} - 1$$

* $$\boxed{\frac{\Delta TO}{TO_1} = \frac{A_2}{B_2}\Big/\frac{A_1}{B_1} - 1}$$

$$\boxed{\begin{aligned} A &= \frac{M_O}{L_O} + \text{JME rate} + 1 \\ B &= \frac{M_I}{L_I} + \text{JME rate} + 1 \end{aligned}}$$

E = Comparative Measure of Effectiveness

$$\boxed{E = \frac{TO_1^{act} + \left[\frac{\Delta TO}{TO_1}\right] TO_1^{act} - TO_2^{act}}{TO_2^{act}}}$$

$\frac{6.24}{5.84} \times \frac{9.11}{9.51} - 1$

1.068 − .03

5.84 | 6.24
584
4000
3504
4960
4672
288

3.2%

Increase = 7%

2.4
.032

.958

58
12
468

9.51 | 9.1100
8559
5510
4755
7550

1.068
.958
8544
5340
9702
1.032144

TURNOVER ANALYSIS

$$\left.\begin{array}{ll} M_o & - \text{material} \\ L_o & - \text{Labor} \\ H_o & - \text{I.M.E.} \end{array}\right\} \text{in Output}$$

$$\left.\begin{array}{ll} M_I & - \text{Material} \\ L_I & - \text{Labor} \\ H_o & - \text{I.ME} \end{array}\right\} \text{in Inventory}$$

$$TO = \frac{\text{output}}{\text{Inventory}} = \frac{M_o + L_o + H_o}{M_I + L_I + H_I}$$

$$\frac{M_o}{L_o} = Q \quad ; \quad M_o = QL_o$$

$$\frac{M_I}{L_I} = P \quad ; \quad M_I = PL_I$$

$$H_o = (R-1)\,L_o \qquad\qquad R = \text{IME rate} + 1$$

$$H_I = (R-1)\,L_I$$

$$TO = \frac{QL_o + L_o + (R-1)L_o}{PL_I + L_I + (R-1)L_I}$$

$$TO = \frac{(Q+R)}{(P+R)}\frac{L_o}{L_I}$$

$$TO_2 - TO_1 = \frac{(Q_2+R_2)}{(P_2+R_2)}\frac{L_o}{L_I} - \frac{(Q_1+R_1)}{(P_1+R_1)}\frac{L_o}{L_I}$$

$$\Delta TO = \frac{(Q_2+R_2)(P_1+R_1) - (Q_1+R_1)(P_2+R_2)}{(P_2+R_2)(P_1+R_1)}\;\frac{L_o}{L_I}$$

compare TO_2

TO_1

multiply $\left[\frac{\Delta TO}{TO_1}\right] \times TO_1^{act} = TO_1'$

fair comparison $TO_2 - TO_1' - TO_1$

Mf

Comparative measure of Efficiency = E

~~$E = \frac{TO_2^{act} - TO_1'}{}$~~

$$E = \frac{TO_1 - TO_2^{act}}{TO_2^{act}}$$

①

$$TO = \frac{M_0 + L_0 + H_0}{M_I + L_I + H_I}$$

~~c = Int rate~~

C - 1 = Int rate

C = Int rate + 1

$$H_0 = (C-1)L_0$$

$$H_I = (C-1)L_I$$

$$M_0 = Q L_0, \quad \text{or} \quad Q = \frac{M_0}{L_0}$$

$$M_I = P L_I \qquad P = \frac{M_I}{L_I}$$

$$TO = \frac{QL_0 + L_0 + CL_0}{PL_I + L_I + CL_I} = \frac{(Q+1+C)L_0}{(P+1+C)L_I}$$

$$TO_2 - TO_1 = \frac{(Q+1+C_2)L_0}{(P+1+C_2)L_I} - \frac{(Q+1+C_1)L_0}{(P+1+C_1)L_I}$$

$$= \frac{(P+1+C_1)(Q+1+C_2)L_0 - (Q+1+C_1)(P+1+C_2)L_0}{L_I\,(P+1+C_2)(P+1+C_1)}$$

$$= \frac{L_0}{L_I}\;\frac{(P+1+C_1)(Q+1+C_2) - (Q+1+C_1)(P+1+C_2)}{(P+1+C_2)(P+1+C_1)}$$

ⓒ

$$TO = \frac{QL_o + L_o + (C-1)L_o}{PL_I + L_I + (C-1)L_I}$$

$$TO = \frac{QL_o + CL_o}{PL_I + CL_I} = \frac{L_o\,(Q+C)}{L_I\,(P+C)}$$

$$TO_2 - TO_1 = \frac{L_o\,(Q+C_2)}{L_I\,(P+C_2)} - \frac{L_o}{L_I}\,\frac{(Q+C_1)}{(P+C_1)}$$

$$= \frac{L_o}{L_I}\left[\frac{(Q+C_2)}{(P+C_2)} - \frac{(Q+C_1)}{(P+C_1)}\right]$$

$$= \frac{L_o}{L_I}\left[\frac{(P+C_1)(Q+C_2) - (Q+C_1)(P+C_2)}{(P+C_1)(P+C_2)}\right]$$

$$= \frac{L_o}{L_I}\left[\frac{\cancel{PQ} + C_1Q + C_2P + \cancel{C_1C_2} - \cancel{QP} - C_1P - QC_2 - \cancel{C_1C_2}}{(P+C_1)(P+C_2)}\right]$$

$$= \frac{L_o}{L_I}\left[\frac{C_1Q + C_2P - C_1P - C_2Q}{(P+C_1)(P+C_2)}\right]$$

$$= \frac{L_o}{L_I}\left[\frac{C_1(Q-P) - C_2(Q-P)}{(P+C_1)(P+C_2)}\right]$$

$$= \frac{L_o}{L_I}\left[\frac{(C_1-C_2)(Q-P)}{(P+C_1)(P+C_2)}\right]$$

$$C_2 = SC_1 \qquad S = \frac{C_2}{C_1}$$

$$\Delta TO = \frac{L_0}{L_I}\left[\frac{(C_1 - SC_1)(Q-P)}{(P+C_1)(P+SC_1)}\right]$$

$$\cancel{= \frac{L_0}{L_I}\Big[}$$

In normal Business $P > Q$

If this is so

for $S > 1$

$$\Delta TO = \frac{L_0}{L_I}\left[\frac{(-)(-)}{+}\right] = +$$

$S = 1$

$$\Delta TO = \frac{L_0}{L_I}\left[\frac{0}{-}\right] = 0$$

$S < 1$

$$\Delta TO = \frac{L_0}{L_I}\left[\frac{(+)(-)}{+}\right] = -$$

Evaluation of Turnover Variation

①	②
$M_o = 37\%$ MCO	$M_o = 50\%$ MCO
$L_o = 14\%$ MCO	$L_o = 11\%$ MCO
$\frac{M_o}{L_o} = 2.64$	$\frac{M_o}{L_o} = 4.55$
$IME = 2.2$	$IME = 2.2$
$M_I = 65\%$ SCI	$M_I = 65\%$ SCI
$L_I = 11\%$ SCI	$L_I = 11\%$ SCI
$\frac{M_I}{L_I} = 5.91$	$\frac{M_I}{L_I} = 5.91$
$A = 2.64 + 2.20 + 1.00$ $= \underline{\underline{5.84}}$	$A = 4.55 + 2.20 + 1.00$ $\underline{\underline{7.75}}$
$B = 5.91 + 2.20 + 1.00$ $= \underline{\underline{9.11}}$	$B = 5.91 + 2.20 + 1.00$ $= \underline{\underline{9.11}}$

$$\frac{\Delta TO}{TO_1} = \left(\frac{7.75}{5.84} \cdot \frac{9.11}{9.11}\right) - 1$$

if only IME changes and $IME_1 = 2.2$, $IME_2 = 2.6$

$A_1 = 5.84$
$B_1 = 9.11$

$A_2 = 6.24$
$B_2 = 9.51$

$$\frac{\Delta TO}{TO_1} = .032$$

Each Business has an $\left[\frac{A}{B}\right]$

$$C = \frac{A}{B} = \frac{M_0/L_0 + \text{IME rate} + 1}{M_I/L_I + \text{IME rate} + 1}$$

$$\boxed{C = \frac{M_0/L_0 + \text{IME rate} + 1}{M_I/L_I + \text{IME rate} + 1}}$$

for comparing two businesses:

E = measure of Effectiveness

$$\boxed{E = \frac{TO_1^{act} + \left(\frac{C_2}{C_1} - 1\right) TO_1^{act} - TO_2^{act}}{TO_2^{act}}}$$

$$C = \frac{\frac{M_0}{L_0} + \frac{H_0}{L_0} + \frac{L_0}{L_0}}{\frac{M_I}{L_I} + \frac{H_I}{L_I} + \frac{L_I}{L_I}} = \frac{\frac{M_0 + H_0 + L_0}{L_0}}{\frac{M_I + H_I + L_I}{L_I}} = \frac{M_0 + H_0 + L_0}{L_0} \cdot \frac{L_I}{M_I + H_I + L_I}$$

$$TO = \frac{M_0 + H_0 + L_0}{M_I + H_I + L_I};$$

$$C = \frac{M_0 + H_0 + L_0}{M_I + H_I + L_I} \cdot \frac{L_I}{L_0} = TO \frac{L_I}{L_0}$$

$75/MKW
85 MKW/unit
375
600
6375 in 1953 avg $6500/unit
1954 avg $7000/unit

6500
70
455,000
1953

7000
70
490000
1954

$2 \overline{)450000}$
225 000 = avg inv Effect 1953

$2 \overline{)490000}$
245 000 = avg inv Effect 1954

avg inv = 35 000 000

$\Delta I = .7\%\ I$ 1953
$\Delta S = 3 \times .7\%\ I$ 1954 $= 2.1\%\ I$
$\Delta O = \frac{500000}{100000000} = .5\%$ in 1953
$\Delta O = .5\%$ in 1954

avg TO = 2.5 $\Delta TO = .5 + .7 = 1.2\% \times 2.5 = .03$ 1953
$\Delta TO = .5 + 2.1 = 2.6\% \times 2.5 = \underline{.06}$ 1954

$\ell = f(t)$

Area $= \int_0^T \ell\, dt = \int_0^T f(t)\, dt$

$m = g(t)$

Area $= \int_0^T m\, dt = \int_0^T g(t)\, dt$

find L_I such that

$$\int_0^T L_I\, dt = \int_0^T f(t)\, dt$$

$$L_I T = \int_0^T f(t)\, dt$$

find M_I such that

$$\int_0^T M_I\, dt = \int_0^T g(t)\, dt$$

$$M_I T = \int_0^T g(t)\, dt$$

when $t = T$

$g(t) = M_0$

when $t = 0$

$g(t) = 0$

when $t = T$

$f(t) = L_0$

when $t = 0$

$f(t) = 0$

$l = kt$

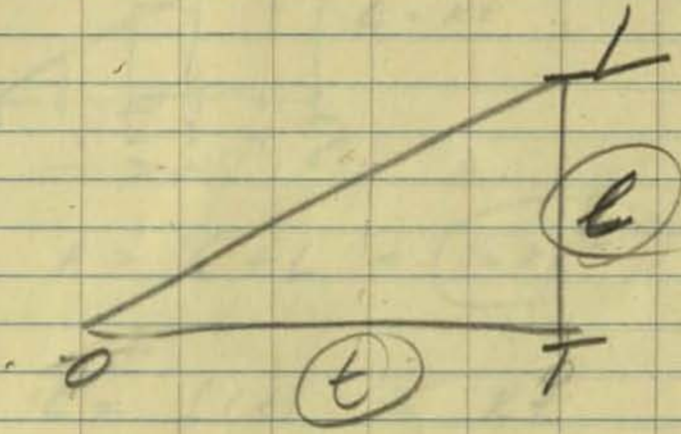
$$\int_0^T l\,dt = \int_0^T kt\,dt$$

$$= \left[\frac{kt^2}{2} + C\right]_0^T$$

$$= \frac{kT^2}{2} + C - C = \frac{kT^2}{2}$$

$$\left.\begin{aligned} L &= kT \\ \frac{L}{T} &= k \end{aligned}\right\} = \frac{L}{T}\frac{T^2}{2} = \frac{LT}{2}$$

$L_z t = f(t) t$



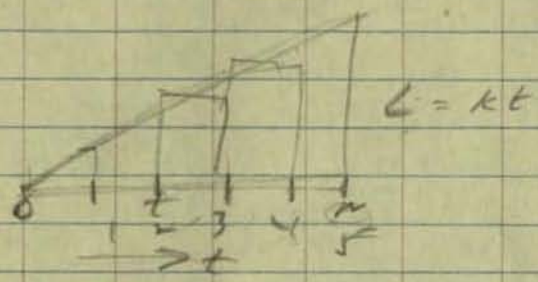
$L = K t$ $l = KT$

$\int_{t0}^{T} K t K = \int K^2 t$

$\frac{1}{2} LT$ $\frac{K^2 t^2}{2} + C \Big]_0^T$

$\frac{K^2 t^2}{2}$ $\frac{K^2 T^2}{2 T^2}$

$K = \frac{L}{T}$



$A = \frac{1}{2} tL = \boxed{\frac{1}{2} kt^2}$

$L = f(t) = kt$

$\text{Area} = \sum_0^n f(t)\, t = \sum_0^n kt^2$

~~if n = 5~~ ~~$= \int kt^2$~~

if n = 5

$\text{Area} = \sum_0^5 kt^2$

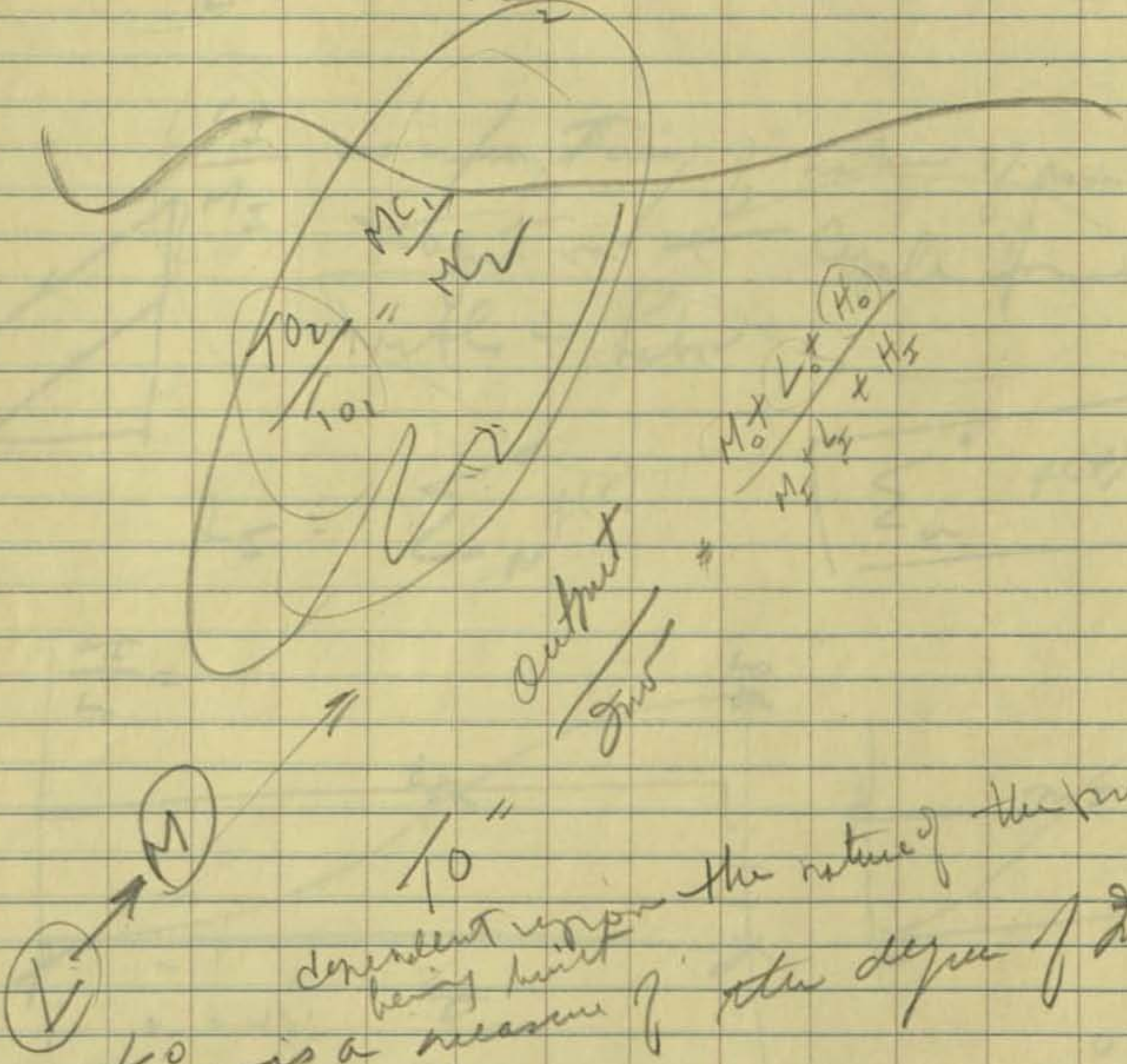
$K + 4K + 9K + 16K + 25K$

$\text{Area} = \boxed{55\ K}$

$L = f(t)$

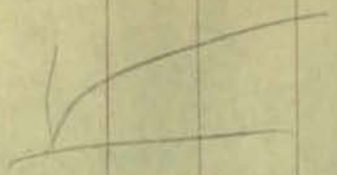
$A = \int_{-T}^{0} L \, dt$

$$\frac{TO_1}{TO_2} = \frac{\frac{\text{output}_1}{\text{Inv}_1}}{\frac{\text{output}_2}{\text{Inv}_2}}$$



$\frac{L_O}{M_O}$ is a measure of the degree of integration of a specific business dependent upon the nature of the product being built

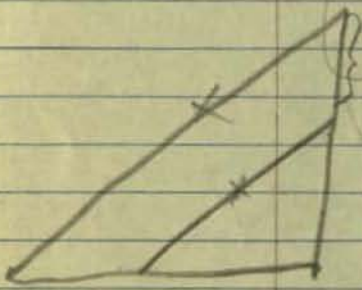
$\frac{L_{O2}}{M_{O2}} > \frac{L_{O1}}{M_{O1}}$ if business | " T



for further analysis assume

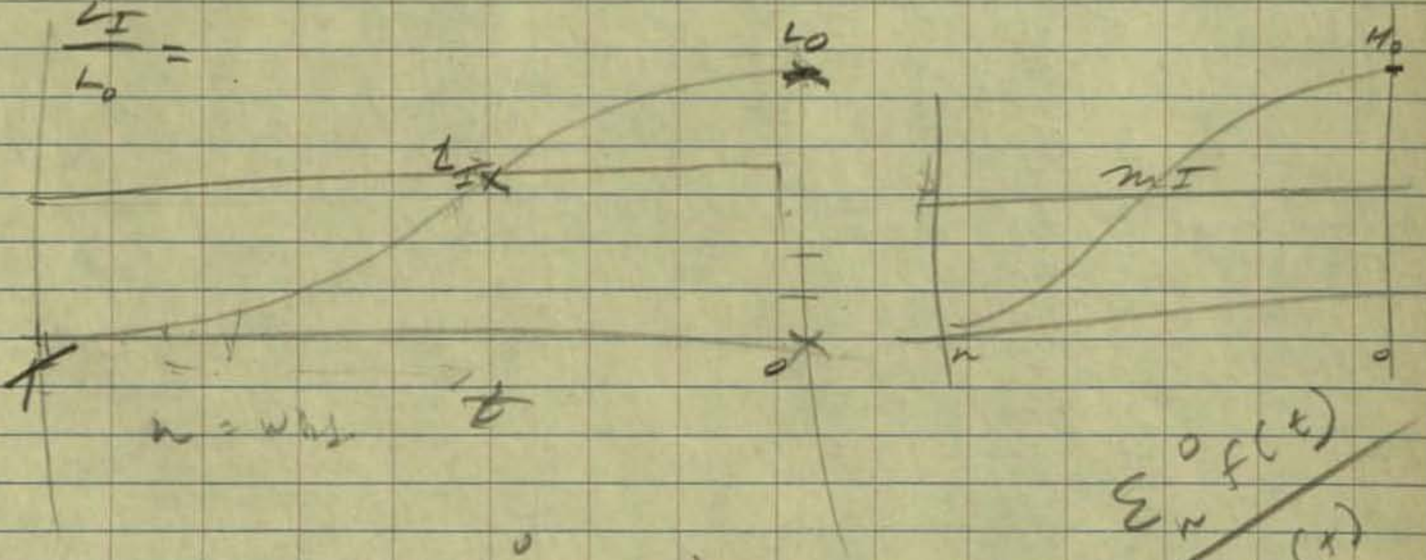
$\frac{H}{L}$ = Constant

$\frac{L_I}{M_I}$ is a function of nature of product + subject in ~~+~~ cycle for metal + labor



$$L_I = \sum_n^0 f(t)$$

$$\boxed{\sum_n^0 f(t)\,t}$$



$$M_I = \sum_n^0 g(t)$$

$$\frac{L_I}{M_I} = \frac{\sum_n^0 f(t)}{\sum_n^0 g(x)}$$

TO.

$$\frac{TO_1}{TO_2} = \frac{(1+R_1)L_{O_1}/M_{O_1} + 1}{(1+R_2)L_{O_2}/M_{O_2} + 1} \times \frac{(1+R_2)L_{I_2}/M_{O_2} + 1}{(1+R_1)L_{I_1}/M_{O_1} + 1}$$

$$TO = \frac{L_o + M_o + H_o}{L_I + M_I + H_I} = \frac{\frac{L_o}{M_o} + 1 + \frac{R L_o}{M_o}}{X}$$

$$= \frac{\frac{(1+R)L_o}{M_o} + 1}{X}$$

$\cancel{\frac{L_I}{M_0}}$

$$I = M_I + L_I + H_I$$

$$O = M_o + L_o + H_o$$

$$T/o = \frac{O}{I}$$

$M_I = K L_I$; $K = \frac{M_I}{L_I}$

$M_o = R L_o$ $R = \frac{M_o}{L_o}$

$H_I = Q L_I$ $Q =$ Idle rate

$H_o = Q L_o$ $P = 1 + Q$

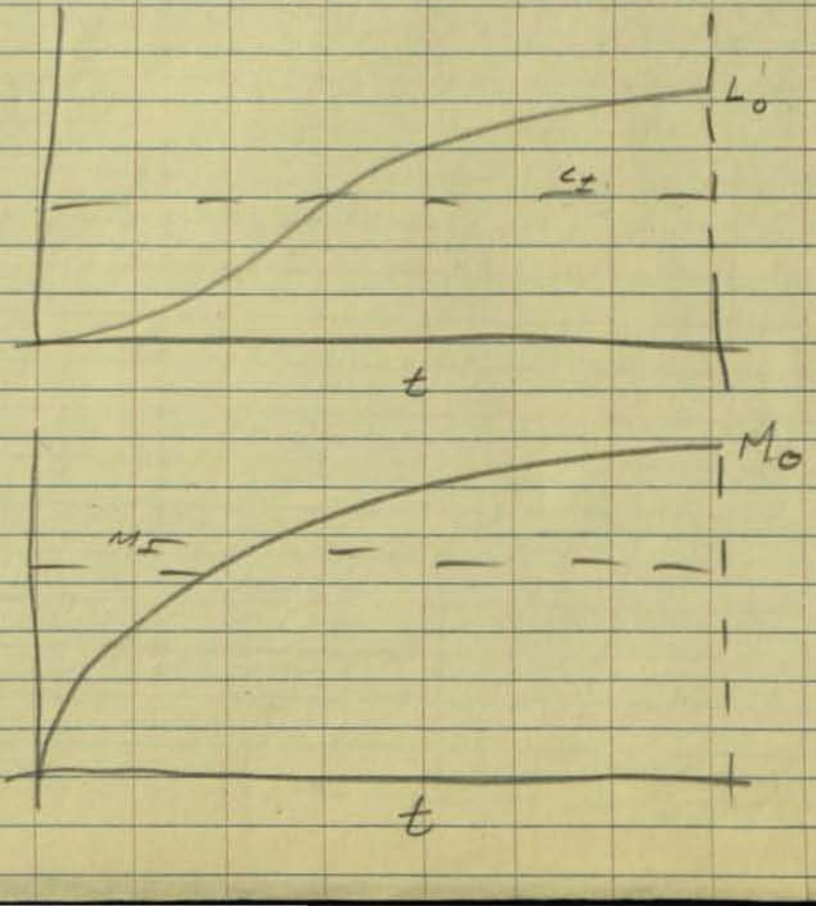
$$T/o = \frac{R L_o + L_o + Q L_o}{K L_I + L_I + Q L_I} = \frac{L_o}{L_I} \frac{(R+1+Q)}{(K+1+Q)}$$

$$T/o = \frac{L_o}{L_I} \frac{(R+P)}{(K+P)}$$

$$\frac{L_I}{M_I} = \frac{\Sigma_n^0 f(t)}{\Sigma_n^0 g(t)} \quad \frac{L_0}{M_0}$$

$\frac{L_0}{M_0}$ is an inherent part of a business

measures nature of product
degree of integration



Let's simplify —
Assume

$M_I = M_0$

$L_I = \frac{L_0}{2}$

$\frac{M_I}{L_I} = \frac{2 M_0}{L_0}$

DMB rate = 2.00

$\frac{M_0}{L_0} = \frac{2.5}{1}$

$$C = \frac{2.5 + 2.0 + 1}{5.0 + 2.0 - 1} = \frac{5.5}{8.0}$$

Better management

Set up Eco Ord Qty Calc
by Linear Programming Techniques.

wish to minimize net yearly cost

Cost generating function

x_1 = qty ordered

$= Ax_1 + \frac{B}{x_1}$

where A = Inventory cost function

B = Ordering + setup cost function

$x_1 \leq U$ U = yrly usage

$x_1 \geq q$ q = min ord. qty

sometimes [$\frac{x_1}{q} = I$ I = integer

$x_1 \geq 0$

$x_1 = I$ I = integer

p = price differential for quantity purchases

(20)

Application of a generalized factory model

1) Test new scheduling tech -
2) Test new dispatching policies
3) Test ~~new~~ changed mach L/O or alternate routings
4) Test changed refg cycles
5) Test revised mtl movmt plans
6) Test addition of new mch
7) Test for schedule feasibility

SCHEDULING

In order to determine an optimum input schedule it is necessary to have some means of testing various schedules and to develop a plan or technique for finding the best one.

The most straight forward approach to the evaluation of a schedule would seem to be the creation of a mathematical model which would simulate the behavior of the factory under study. Then, the next step would be an evaluation based upon the results of the factory model operating on a certain input schedule.

With the factory model and the evaluation equation determined, the only remaining variable is the input schedule itself. In the factory, output is normally specified in terms of customer wants or anticipated wants; this usually establishes a quantity of a specific product desired at a specific date. Therefore, the end result, if within the capacity of the shop, is completely specified and flexibility exists only in the starting date of a lot through the shop and in the priority system used within the factory to determine individual job sequence.

Let us look at each of these three phases of schedule determination separately; for convenience we shall start with the evaluation, then discuss the factory model and finally the variation of the input schedule itself. In general the discussion will be centered on a job control operation, since, with either a batch control or a flow control set-up the problem becomes simpler and easier to analyze.

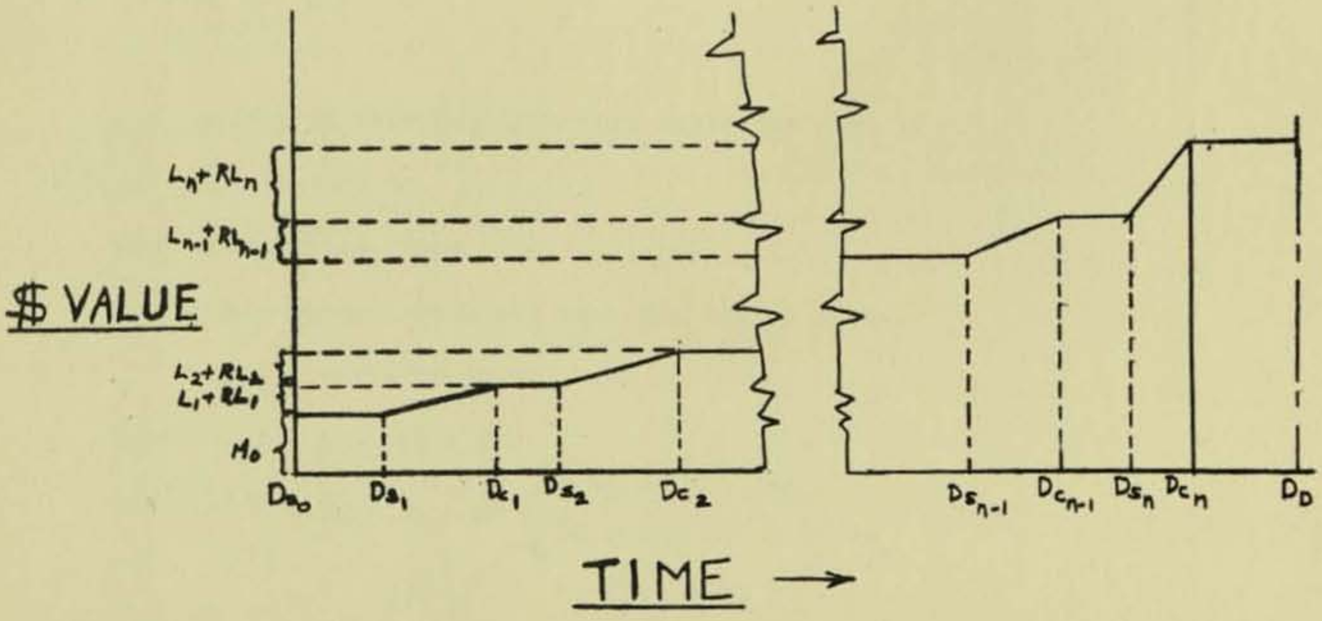
EVALUATION

In evaluating the effects of an input schedule on the factory four measuring sticks seems most significant:

1. Inventory Carrying cost for the lot being manufactured.
2. Equivalent penalty for late completion of the lot.
3. Non-productive man-machine time.
4. Set-up costs.

There is a fifth function - that of the cost of scheduling itself; however, this tends to be inversely dependent upon the lot size which for the sake of simplicity, is being omitted from this discussion. Therefore, it will be assumed that the actual cost of preparing a schedule will be identical in all cases.

The cost of carrying inventory through the entire cycle can be represented in two different ways. The more accurate is as follows:



$$\begin{aligned}\text{Cost of Carrying INV.} = I \Big\{ & (D_{c_n} - D_{s_o})\, M_o + (D_{c_1} - D_{s_1})(L_1 + RL_1)\, \tfrac{1}{2} \\ & + (D_{c_n} - D_{c_1})(L_1 + RL_1) + (D_{c_2} - D_{s_2})(L_2 + RL_2)\tfrac{1}{2} + (D_{c_n} - D_{c_2})(L_2 + RL_2) \\ & + \ldots + (D_{c_{n-1}} - D_{s_{n-1}})(L_{n-1} + RL_{n-1})\tfrac{1}{2} + (D_{c_n} - D_{c_{n-1}})(L_{n-1} + RL_{n-1}) \\ & + (D_{c_n} - D_{s_n})(L_n + RL_n) \Big\} + (\text{if } D_d > D_{c_n}), (D_d - D_{c_n})(M_o + L + RL)\end{aligned}$$

Where:

Ds_o = Date material received

D_{s_1} = Date start 1st operation

D_{c_1} = Date completed 1st operation

D_d = Date due complete

M_o = Material Cost

L_1 = Direct Labor 1st operation

R = Ratio of IME to Direct Labor

$L = \sum_{i=1}^{n} L_i$

I = Cost of Carrying Inventory ratio per day.

A Good Approximation is:

Cost of Carrying INV. = IAC

A = the Average Inventory over the entire cycle.

C = Entire cycle in days.

Where: $A = M_o + \frac{1}{2}(L + RL)$

$$C = Dc_n - Ds_o + \begin{cases} 0 \text{ if } Dd \leq Dc_n \\ Dd - Dc_n \text{ if } Dd > Dc_n \end{cases}$$

Either of these two equations may be used for inventory evaluation. The second method is generally to be preferred for simplicity and ease of manipulation.

There are three areas of cost which need to be investigated in order to determine the equivalent penalty for late delivery. If a finished product is being shipped directly to a customer, the customer dissatisfaction may be measured through a penalty clause in the contract; however, if there is no such clause then an estimate must be made of the losses which may be suffered through the customer's not obtaining a delivery on the date desired; this might be obtained by estimating the amount which you would be willing to pay to avoid late delivery. Where the product is used as a portion of a final assembly this factor could be a measure of the direct extra cost which would be caused in the assembly department in order to avoid late delivery of the final product. The net cost of customer dissatisfaction can be expressed as $(D_c - D_d)$ FR, where D_c equals the actual date the part is completed, D_d equals the date due complete, F equals the full value of the part, and R equals the customer dissatisfaction ratio per unit product value per day.

The second cost of late delivery is involved in the necessity for carrying the inventory for this lot for a period of time longer than planned. This has been covered in the cost of inventory for the product, by including the time period $(D_{c_n} - D_d)$.

The third area of cost for late delivery is the cost of carrying inventory for other parts which are used together with this part. This is only applicable where the product is used in further assembly. The cost is equal to $(D_c - D_d)$ BI where B equals the inventory value, prior to assembly, of all parts held up pending delivery of this part and I equals the cost of carrying inventory ratio.

The next basic function to be investigated is the non-productive cost when the man-machine combination is idle. The first area here is the payment of funds to operators who have not been able to produce goods because of insufficient part availability. This can be evaluated as $(T_i)(W_m)$. Where T_i equals the idle time in minutes and W_m equals the rate of pay per minute.

The second factor is somewhat more complex in that by the machines not having produced useful goods during the time period T_i a certain loss in output product has been experienced. This loss in output is only significant in that normal profit may have been lost and non-direct expenses not liquidated. This may be expressed as $(VR + O_h W_m) T_i$

Where: V = Replacement value of the machine tool

R = Required return on Investment per minute and

O_h = Overhead to Direct Labor ratio

The fourth and last of the evaluation factors is the needed set-up costs. This can most readily be obtained through a direct comparison of the total set-up dollars expended under one schedule as against the total set-up dollars expended under a different schedule. In some jobs, especially those that use special purpose tooling, this factor may be dropped since there are few opportunities for reduction in set-up costs, except through change in lot size, which has been omitted from this discussion. It should be understood that set-up costs are considered to include not only make-ready charges but also tear-down, clean-up, and put-away costs. Other ways in which this cost may be influenced is by the combining of set-ups on similar jobs and the splitting of jobs for load purposes thereby causing additional unplanned set-ups. This can be expressed as:

$$\sum_{i=1}^{n} \sum_{j=1}^{r} S_{ij}$$

Where S = actual set-up charge experienced on a given job and a given operation.

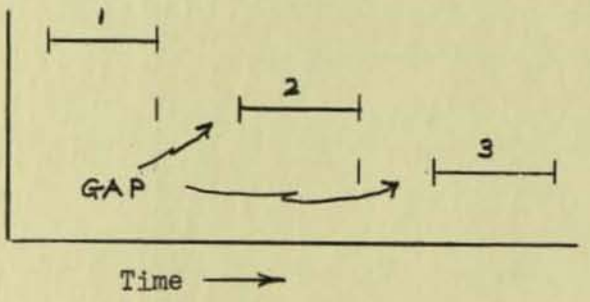
FACTORY MODEL

In preparing a factory model it was decided to imitate as closely as seemed practical actual operation, not the ideal or storybook version. This means that recognition must be made of the effect human errors have on the output of the factory. In preparing the model the operation of a factory seemed to divide itself into three areas. The first is the actual job selection method and is intimately related with the priority system associated with the schedule; this is frequently called dispatching or scheduling. The second activity is the actual transformation of the product through physical, chemical, or electrical means into something different from its original state. This is usually known as machining, assembly, or processing. The third area is the physical movement of the material from one location to another. This is material handling or transportation. Each of these basic areas will now be analyzed.

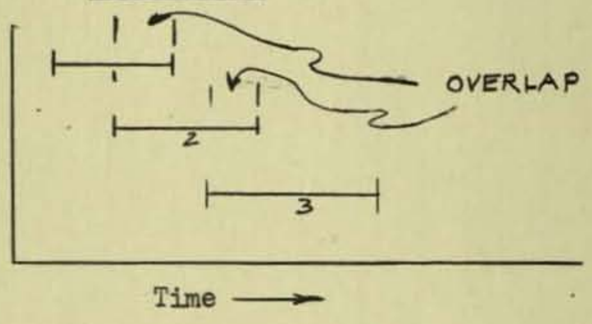
The dispatching method used in many job shops operates as follows:

A man comes to the dispatcher's window and requests the assignment of a new job; therefore, the man is the forcing function. The dispatcher has a record by operation station of the various jobs which are available for that station at that specific time. In accordance with the existing priority system the dispatcher selects the most urgent job and assigns that to the operator. At some later time the dispatcher will be notified that the job is ready to move to the next station; this may be done by having the operator come to the window for a new job. At this time the dispatcher determines what the next station is and directs a material handler to transport the material to that area. When the material has been delivered to the next station the dispatcher is informed by the material handler and a record is made at that station that the job is available. This basic selection technique will vary somewhat between different factories. However, the key point is that no job can be moved until it has been operated upon and that no operation can be started unless the material is at that station. This can be modified by using "lap-phasing" instead of the more usual "gap-phasing". They can best be differentiated by looking at a graph of factory progress under both plans:

GAP PHASING



LAP PHASING



In this discussion "gap-phasing" will be assumed. The problems of "lap-phasing" are numerous such as determining the number of individual deliveries and therefore is not too frequently used in a job control shop; it is frequently employed in a batch control operation and reaches its ultimate in the flow control shop when the lot size is unity. The variable factors to be considered in the dispatching mechanism include the delay times in receiving information. Dispatching in the batch or flow control shop is of a somewhat simpler nature. There, the starting date may be determined a week or more in advance and it is anticipated that the various consecutive operations will be performed on these jobs maintaining the original sequence. Therefore in these areas a dispatcher only has to control the starting sequence selection. It is even possible to treat the entire group of operations as being performed at a single station; this is especially true where conveyor belts are used.

The station operation model predicts the performance of certain specific tasks during a finite time interval. There are two basic phases to look at.

First is the fixed or pattern data such as

Starting time = T_o

Initial quantity = x

Set-up time = e

Time per unit = p

If the operation were perfect and there were no "lap phasing" or human or machine variations to deal with, it would be a simple matter to predict the completion time (T_c). $T_c = T_o + e + xp$

However we do not face any such ideal situation. The following "noise" factors severely affect the completion time for a lot and their specific impact is on a somewhat random basis.

Operator efficiency ratio = f, $f > O$

Machine breakdown = b, $b = o$ for indicating machine availability.

$b > o$ indicates time delay until machine is available.

Operator absenteeism = a, $a = o$ for indicating operator availability.

$a > o$ indicates time delay until operator is available.

Spoilage ratio to original quantity = s, $s \geq o$

Re-work ratio to original planned time = r, $r \geq o$

Material, tool, blueprint and paperwork availability = m , $m = o$ for indicating availability of all factors.

$m > o$ indicates time delay until all factors will be available.

Therefore, the actual equation which must be used for predicting the anticipated completion time (T'_c), still omitting lap phasing is:

$$T'_c = T_o + \frac{1 + r}{f} (e + xp) + b + a + m$$

and at T'_c, $x' = (1 - s)x$,

First is the fixed or pattern data such as

Starting time = T_o

Initial quantity = x

Set-up time = e

Time per unit = p

If the operation were perfect and there were no "lap phasing" or human or machine variations to deal with, it would be a simple matter to predict the completion time (T_c). $T_c = T_o \not- e \not- xp$

However we do not face any such ideal situation. The following "noise" factors severely affect the completion time for a lot and their specific impact is on a somewhat random basis.

Operator efficiency ratio = f, $f > 0$

Machine breakdown = b, $b = o$ for indicating machine availability.

$b > o$ indicates time delay until machine is available.

Operator absenteeism = a, $a = o$ for indicating operator availability.

$a > o$ indicates time delay until operator is available.

Spoilage ratio to original quantity = s, $s \geq o$

Re-work ratio to original planned time = r, $r \geq o$

Material, tool, blueprint and paperwork availability = m , $m = o$ for indicating availability of all factors.

$m > o$ indicates time delay until all factors will be available.

Therefore, the actual equation which must be used for predicting the anticipated completion time (T'_c), still omitting lap phasing is:

$$T'_c = T_o \not- \frac{1 \not- r}{f} (e \not- xp) \not- b \not- a \not- m$$

and at T'_c, $x' = (1 - s)x$,

where x' = completed quantity and each factor is determined by an appropriate probability distribution.

One important feature of this probability arrangement is that no single run-through of a schedule will be sufficient for evaluation. It will be necessary to use a statistically determined number of tries or samples in order to predict with, say 90% accuracy, the mean evaluation for a given schedule.

However, it should be noted that each of these "noise" factors can, with the data which is available, be statistically determined and need not be guessed or estimated. The accuracy with which the probability distributions for these noise factors is established will, to a great degree, determine the usefulness of the final results.

The third function in the factory, that of material handling, can also be analyzed statistically, if necessary. In a batch control or flow control operation where automatic or semi-automatic movement exists, this transportation mechanism is exceedingly simple in that it is an essentially predictable function. However, in the job control shop, indications are that this can be a random relationship not fixed by the source station and delivery station or by their distance, time of day, or any other determinable factor. All this means is that the transportation time may have to be derived and used in the same manner as the noise factors.

VARIATION OF INPUT SCHEDULING

The basic objective of all this evaluation and factory simulation is the improvement of the input schedule itself. Two basic approaches suggest themselves: one is the possibility of random variation of the sequence of items in the input schedule, thereby providing a set of different priority systems. Each new sequence that is attempted should result in some change in the net evaluation. However, the difficulty here arises in the tremendous magnitude of the available permutations. For instance, for just 100 jobs the total number of arrangements for a single operation is 10^{158}. If there were, say 10 operations to be performed on each job, then this number would have to be raised to the tenth power to cover all of the various possibilities. Even with the fastest computer on the market today such a number of trials is not economically feasible especially since the time consumed would be such to make the data old before an answer was obtained. A second possible fallacy in this random arrangement approach is the absolute magnitude of the noise factors compared to the average cost variances. It should be possible statistically to compute at what magnitude of the noise factors the cost variances are insignificant.

However, this above technique might be applied through random arrangement of stratified data. For instance, if the various jobs to be manufactured were arranged in sequence based upon their due complete date and the amount of work left to be performed then it would seem rational to establish rules that no job may be moved more than n positions down this stratified table. This approach can be even further simplified by dividing the jobs into a set of groups of n items each. Then, within the group random arrangements might be tested, but no job could be shifted to a different group. However, even this approach leads to voluminous trials since if there were 100 jobs and 10 jobs to each sub-group there would be $(3.6 \times 10^6)^{10}$ trials. Another possibility is testing of each group independently and then fixing permanently the results of this group prior to the testing of the next group. However, this would have to be proven as statistically valid. All of these approaches require the weekly (or other short period) re-analysis in order to determine the comparative priority numbers.

The second basic way of approaching the variation of the input schedule is by using an Operations Research type analysis. This involves a study of the effect that various input factors have on the output factors and by appropriate correlation establishing the anticipated variation in output from a specific change in input. Certain examples may be cited which explain more clearly this approach. As stated previously, an input schedule specified certain factors. First, it establishes the quantity desired at a certain date. Next, it provides for each item a starting date supposedly selected so as to meet the due complete date. Third, associated with the schedule, is a basic priority system which gives each job in the factory a comparative preference. Since, in normal operation the quantity and finish date are fixed the only variation that can be made is the starting date and the nature of the priority system itself. Now if an adequate factory model exists it should be possible to intelligently vary the basic manufacturing cycles (hence the starting dates) for the various items. The examination of these results should give excellent clues as to what the optimum cycle should be for each item. Another series of tests might be conducted having the factory model choose the jobs in accordance with different priority systems such as dispatching by due complete date, by starting date, by starting date for each operation, by selected numbers, or by a combination of due date and amount of work to be done. Upon completion of these studies it would seem to be statistically possible to determine for a specific plant the best priority system to use. These studies need not be done every week, but could be performed at semi-annual intervals or as the key factors changed.

There is a further advantage to this approach in that once an effective factory model exists it would be relatively easy to pre-compute the effect changing product mix or changing output would have on the factory.

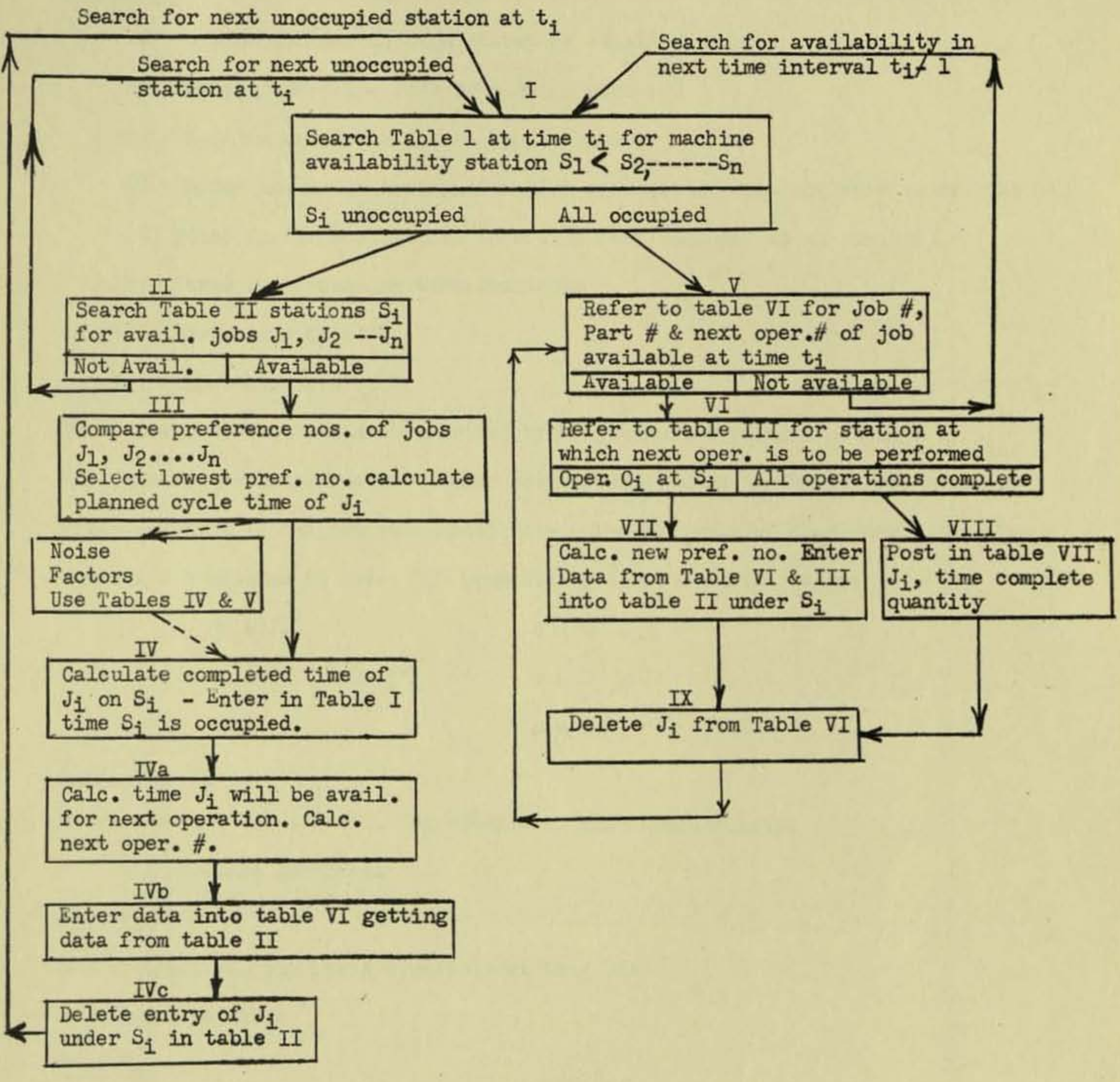
ANALYSIS

From the foregoing paragraphs it seems reasonable to conclude that excellent savings might be realized from the creation of an effective factory model associated with a good evaluation plan. This entire plan must be converted to a detailed computer program in order to obtain a realistic test. It is essential that the time per run be very brief so that multiple reviews will be physically and economically feasible.

The potential gain seems great and further investigation using a computer appears to be extremely desirable.

In order to provide experience on the application of computers to this basic scheduling problem it was decided to try to imitate manually the computer operations on a simple set of data. A concept of the overall flow of information is on the following page:

SCHEDULING INSTRUCTIONS



The tables required are included as exhibits and numbered as follows:

I Machine utilization and status by station number

II Waiting operation file by station number

III Planning and routing data by part number

IV Random number generation function accumulator (not included as an exhibit)

V Noise factor statistical selection (not included as an exhibit)

VI Parts in process by time available

VII Evaluation data

VIII Input schedule

The operations required are described briefly with the results obtained in the specific problem studied. These results are posted in the tables concerned with asterisks to indicate the added data. For the sake of simplicity the noise factors are assumed to have 100% probability for the listed value:

$f = 1.0$

$b = 0$

$a = 0$

$s = 0$

$r = 0$

$n = 0$

Step 1.

Examine time .1 in table I. for example machine availability:

All machines occupied.

Step 2.

Search table VI. for parts available at time .1:

None available

Step 3.

Repeat for time .2:

All machines occupied, no parts available.

Step 4.

Search table I. for machine available at time .3:

Station 03 is available.

Step 5.

Search table II. for station 03 for parts available:

Jobs M and 0 are available.

Step 6.

Compare preference number jobs available and select that job with lowest preference number:

Job 0 has a preference number of ≠ 47.0; therefore job M with a lower preference number will be placed on station 03.

Step 7.

Calculate length of time station 03 will be occupied in manufacturing job M:

$T_o = e \neq xp = 2.5$

Step 8.

Indicate on table I. machine hours utilized at station 03:

Machine will be occupied from time 0.3 through time 2.7; $T_c = (T_s - .1) \neq T_o$.

Step 9.

Calculate time that part will be avilable for machine operation:

Job M complete at station 03 at time 2.7. Transportation time as obtained from random number table = .5; therefore time available for next operation = 3.2.

Step 10.

Obtain next operation number:

Add operation number in table II. to the quantity 1; therefore the next operation number = 2.

Step 11.

Enter data in table VI. and results of calculations:

Time available, job number, part number, quantity, next operation number and preference number.

Step 12.

Delete entry in table II. under station 03 for job M:

Step 13.

Continue searching table I. for available machine capacity during time .3:

All machines occupied.

Step 14.

Search table VI. for parts available at time .3:

Job F. available part 006 for operation 6.

Step 15.

Refer to table III. for 006, operation 6:

Operation 6 says deliver to destination - part is complete; part is complete at time .3.

Step 16.

Post to table VII:

Part 006 completed.

Step 17.

Delete job F from table VI:

Step 18.

Continue searching table VI for parts available at time .3:

No parts available.

Step 19.

Search table I. and table VI for time .4:

All machines occupied, no parts available.

Step 20.

Search table I. and table VI. for time .5:

All machines occupied, no parts available.

Step 21.

Search table I. at time .6:

Station 01 available.

Step 22.

Search table II. for station 01 for parts available:

Jobs A., C., J., L., and N. are available.

Step 23.

Compare preference numbers and select job with the lowest preference number:

Job A.	+ 32.8
Job C.	+ 71.5
Job J.	- 15.6
Job L.	+ 5.0
Job N.	- 23.9

Therefore job N. is selected for assignment.

Step 24.

Calculate length of time station 01 will be occupied in manufacturing job N:

$T_o = 3.6$

Step 25.

Indicate on table I. machine hours utilized at station 01:

$T_c = 4.4$

Step 26.

Calculate time job M will be available for next operation:

$4.4 + .1 = 4.5$

Step 27.

Calculate next operation number:

$2 \not- 1 = 3$

Step 28.

Enter data in table VI:

Step 29.

Delete entry in table II. for station 01 under job N:

Step 30.

Continue to search table I for unoccupied machine at time .6:

All machines occupied.

Step 31.

Search table VI. for parts available at time .6:

No parts available.

Step 32.

Search tables I and IV for time .7:

All machines occupied, no parts available.

Step 33.

Search tables I and IV for time .8:

All machines occupied, no parts available.

Step 34.

Search tables I and IV for time .9:

All machines occupied, no parts available.

Step 35.

Search table I. for machines available at time 1.0:

All machines occupied.

Step 36.

Search table VI for parts available at time 1.0:

Job D., part 006 available for operation #3.

Step 37.

Refer to table III for part 006:

Operation 3 to be performed at station 02.

Step 38.

Calculate new preference number:

$$\pi' = \pi + SF(e_2 + xp_2) = -3.3$$

Step 39.

Enter data under station 02 in table II:

Job number, part number, preference number, operation number, set up, time per unit, and quantity; data obtained from table II and table IV.

Step 40.

Delete Job D. from table IV:

This process is continued until the week's schedule has been planned.

For this problem the priority system is based on the use of a preference number calculated from the due complete date of the job and the amount of work remaining to be performed. The formula used for calculating the preference number is:

$$\pi = D_d - SF(e + xp)$$

Where:

D_d = date due complete

π = preference number

$$SF = \frac{1}{\text{Mfg. cycle efficiency}}$$

e = set-up time

x = quantity

p = per unit time

M = Mfg. Cycle Efficiency

$$M = \frac{\sum_{j=1}^{r} M_j}{r}$$ where there are "r" jobs possible to manufacture.

$$M_j = \frac{T_j}{R_j}$$

$$T_j = \sum_{i=1}^{n} e_i + xp_i$$

$$R_j = D_{c_n} - D_{s_o}$$ where there are n operations per part.

A good approximation is:

$$M \cong \frac{\dfrac{\left[\sum_{i=1}^{n} e_i + XP_i\right]_{j=1}^{j=r}}{r}}{\dfrac{\sum_{j=1}^{r} C_j}{r}} = \frac{\left[\sum_{i=1}^{n} e_i + XP_i\right]_{j=1}^{j=r}}{\sum_{j=1}^{r} C_j}$$

Where C = planned cycle.

This in effect compares the total planned on machine time to the actual time that the job was in the process of manufacture.

This simple approach to the problem of scheduling production through the use of an electronic computer should provide a good beginning for computer programing. Additional studies will be performed in the near future in an effort to determine the computer time required for performing the necessary calculations as well as an evaluation of the potential savings to be realized.

Burton Grad
Production Control Services Section
2/15/54

BG:D

X - Working time
O - Idle time

TABLE 1 - Machine Utilization

STATION #

TIME	01	02	03	04	05		01	02	03	04	05		01	02	03	04	05
	DAY 1					3.0	X	X		X		4.0	X	X	O		
.1	X	X	X	X	X			X		X					O		
.2	X	X	X	X	X			X		X					X		
.3	X	X	X	X	X			X		X							
.4	X	X		X	X			X		X							
.5	X	X		X	X			X		X							
.6	X	X		X	X			X		X							
.7		X		X	X			X		X							
.8		X		X	X			X	X	X							
.9		X		X	X				O	X							
1.0		X		X	X				O	X							
1.1		X		X	X				O	X							
1.2		X		X	X				O	X	X						
1.3		X		X	X				O		X						
1.4		X		X	X		X	X	O								
1.5		X		X	X		X	O	O								
1.6		X		X	X			X	O								
1.7		X		X	X				O								
1.8		X		X	X				O								
1.9		X		X	X				O								
2.0		X		X	X				O				X	X	X	X	X
2.1		X		X	X				O								
2.2		X		X	X				O								
2.3		X		X	X				O								
2.4		X		X	X				O								
2.5		X		X	X				O								
2.6		X		X	X				O								
2.7		X	X	X	X		X		O								
2.8		X	X	X	X		X		O								
[illegible]		X		X					O		X						

x - Working time
o - Idle time

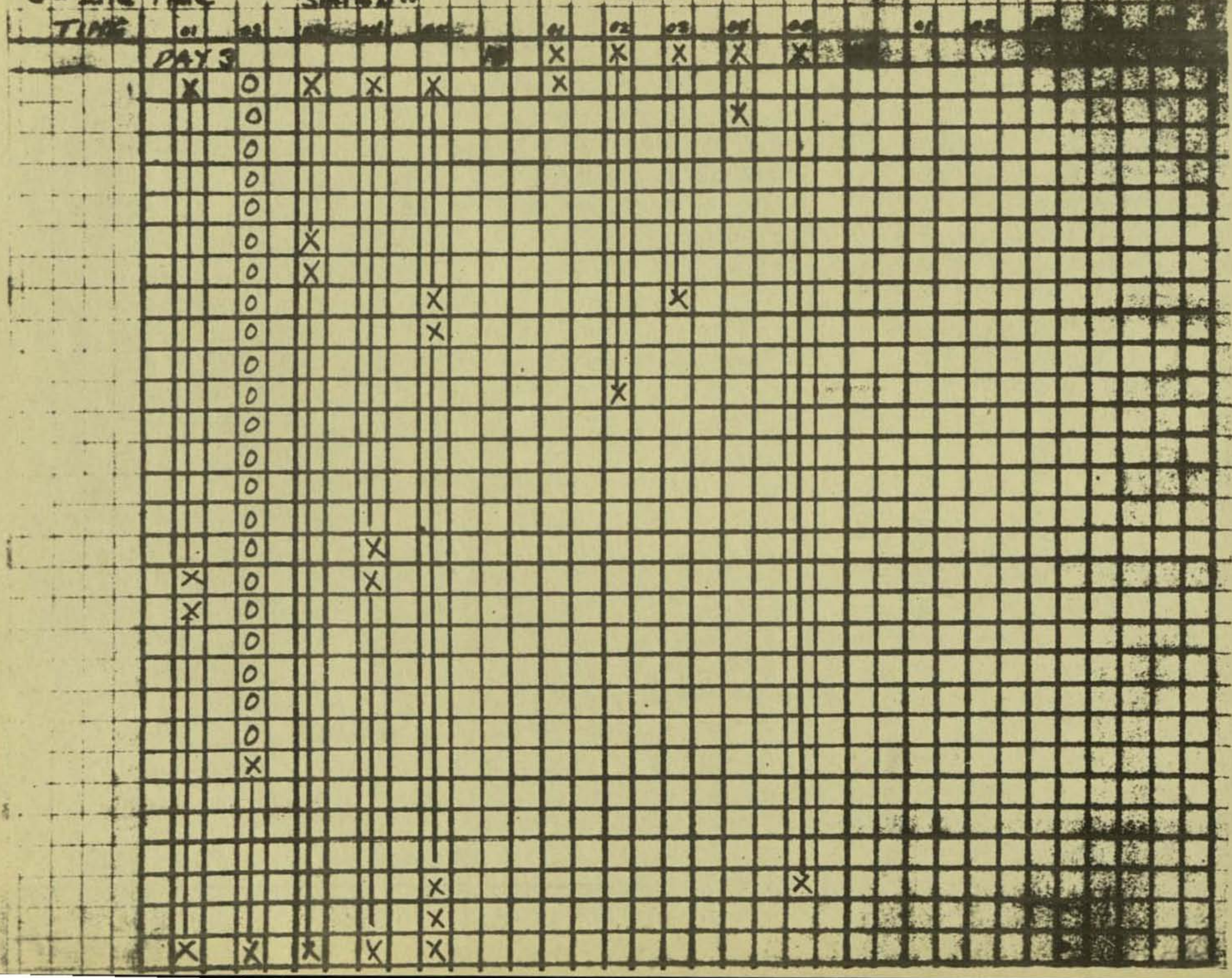
TABLE I - Machine Utilization

STATION #

TIME	01	02	03	04	05		01	02	03	04	05		01	02	03	04	05
	DAY 1					[illegible]	X	O	X	X	X	[illegible]	X	O	X	O	X
	X	X	X	X	X			O					X	O		O	
			X	X	X			O		X			X	O		O	
			O	X	O			O		X				O		O	
			O		O			O	X					O		O	
		X	O		O			O	X	X				O		O	
		O	O		O			O		O				O		O	
		O	O		O			O		O				O		O	
		O	X		O			O		O				O		O	
		O			O			O		O				O		O	
		O			O			O		O				O		O	
		O			O			O		O				O		O	
		O		X	O			O		O				O		O	
		O		X	O			O		O				O		O	X
		O			O			O	X	O				O		O	X
		O			O			O	O	O				O		O	
		O			O			O	O	O				O		O	
		O			O			O	O	O			X	O		O	
		O			O			O	O	O	X		X	O		O	
		O			O		X	O	O	O	X			O		O	
		O			O		X	O	O	O			X	O	X	O	X
		O		X	O			O	O	X							
		O			O			O	O								
		O			O			O	O								
		O			X			O	O								
		O						O	X								
		O						O		X							
	X	O						O		O							
	X	O						O		O							
	X	O	X	X	X		X	O	X	O	X						

TABLE 4 - Machine Utilization

X - Working time
O - Idle time



X – Working Time
O – Idle time

TABLE 1 – Machine Utilization

STATION #

TIME	01	02	03	04	05	01	02	03	04	05	01	02	03
DAY 4													

TABLE 4 - Machine Utilization

-- - working time
o - Idle time

STATION #

TIME 01 02 03 04 05 01 02 03 04 [illegible]

DAY 5

TABLE II

WAITING OPERATION FILE

Job Number	Part Number	Pref. Number	Oper. #	S.V.	Time/Unit	Quan.
Station #01						
A	003	+32.8	1	.2	.7	2
C	004	+71.5	4	.3	.7	1
J	007	-15.6	1	.5	.2	4
L	002	+ 5.0	3	.5	.9	5
N	001	-23.9	2	.3	.9	4
M*	004*	+42.0*	2*	.2*	.6*	3*
H*	005*	+ 9.0*	4*	.2*	.4*	5*
O*	003*	+51.7*	4*	.1*	.4*	1*
E*	002*	+18.9*	5*	.4*	.2*	4*
B*	010*	+50.7*	5*	.5*	.9*	5*
L*	002*	+34.1*	5*	.4*	.2*	5*
R*	001*	+52.4*	2*	.3*	.9*	3*
Station #02						
D*	006*	- 3.3*	3*	.1*	.2*	3*
N*	001*	- 7.3*	3*	.4*	.9*	4*
M*	004*	+51.5*	3*	.1*	.6*	3*
Station #03						
M	004	+31.3	1	.1	.8	3
O	003	+47.0	3	.2	.9	1
J*	007*	-10.0*	2*	.5*	.4*	4*
N*	001*	+ 9.8*	4*	.3*	.6*	4*
D*	006*	+ 4.0*	5*	.4*	.2*	3*
H*	003*	+18.4*	5*	.2*	.6*	5*
Q*	002*	+62.3*	1*	.5*	.6*	2*
S*	010*	+34.1*	1*	.3*	.5*	4*
Station #04						
I	007	+51.7	3	.1	.2	5
B*	010*	+33.2*	4*	.1*	.8*	5*
D*	006*	- .3*	4*	.1*	.3*	3*
K*	008*	+54.7*	5*	.1*	.1*	2*
J*	007*	- 1.0*	3*	.1*	.2*	4*
J*	007*	+13.5*	5*	.2*	.1*	4*
P*	001*	+60.1*	1*	.1*	.5*	2*
R*	001*	+45.6*	1*	.1*	.5*	3*
Station #05						
E	002	+12.5	4	.3	.3	4
K	008	+44.9	4	.5	.9	2
G*	009*	+40.9*	5*	.2*	.3*	5*
J*	007*	+ 2.8*	4*	.5*	.5*	4*
L*	002*	+26.4*	4*	.3*	.3*	5*
I*	007*	+56.4*	4*	.5*	.5*	5*
N*	001*	+21.3*	5*	.5*	.5*	4*
A*	003*	+38.6*	2*	.1*	.9*	2*

Table III

Part Number	Operation	Station Number	S.U.	Oper. Time /pc.
Part # 001	1	04	.1	.5
	2	01	.3	.9
	3	02	.4	.9
	4	03	.3	.6
	5	05	.5	.5
			1.6	3.4
Part # 002	1	03	.5	.6
	2	02	.4	.9
	3	01	.5	.9
	4	05	.3	.3
	5	01	.4	.2
			2.1	2.9
Part # 003	1	01	.2	.7
	2	05	.1	.9
	3	03	.2	.9
	4	01	.1	.4
	5	02	.1	.4
			.7	3.3
Part # 004	1	03	.1	.8
	2	01	.2	.6
	3	02	.1	.6
	4	01	.3	.7
	5	05	.2	.8
			.9	3.5
Part # 005	1	01	.3	.6
	2	03	.5	.2
	3	02	.4	.8
	4	01	.2	.4
	5	03	.2	.6
			1.6	2.6
Part # 006	1	03	.3	.7
	2	01	.1	.4
	3	02	.1	.2
	4	04	.1	.3
	5	03	.4	.2
			1.0	1.8

TABLE III (Cont.)

Part Number	Operation	Station Number	S.U.	Oper. Time /pc.
Part # 007	1	01	.5	.2
	2	03	.5	.4
	3	04	.1	.2
	4	05	.5	.5
	5	04	.2	.1
			1.8	1.4
Part # 008				
	1	01	.5	.7
	2	04	.1	.3
	3	01	.5	.3
	4	05	.5	.9
	5	04	.1	.1
			1.7	2.3
Part # 009				
	1	03	.2	.2
	2	02	.1	.6
	3	05	.3	.2
	4	04	.1	.9
	5	05	.2	.3
			.9	2.2
Part # 010				
	1	03	.3	.5
	2	04	.1	.5
	3	05	.3	.6
	4	04	.1	.8
	5	01	.5	.9
			1.3	3.3

Oper. 6 - across the board
deliveries to destination
part complete

TABLE III (Cont.)

Part Number	Operation	Station Number	S.U.	Oper. Time /pc.
Part # 007	1	01	.5	.2
	2	03	.5	.4
	3	04	.1	.2
	4	05	.5	.5
	5	04	.2	.1
			1.8	1.4
Part # 008				
	1	01	.5	.7
	2	04	.1	.3
	3	01	.5	.3
	4	05	.5	.9
	5	04	.1	.1
			1.7	2.3
Part # 009				
	1	03	.2	.2
	2	02	.1	.6
	3	05	.3	.2
	4	04	.1	.9
	5	05	.2	.3
			.9	2.2
Part # 010				
	1	03	.3	.5
	2	04	.1	.5
	3	05	.3	.6
	4	04	.1	.8
	5	01	.5	.9
			1.3	3.3

Oper. 6 - across the board
deliveries to destination
part complete

TABLE VI

PARTS IN PROCESS

Time Available	Job #	Part #	Quantity	Next Oper. #	Pref. #
.3	F	006	1	6	+61.4
1.0	D	006	3	3	- 8.9
2.9	B	010	5	4	+19.1
3.8	H	005	5	4	- 9.8
4.2	G	009	5	5	+21.3
* 3.2	M	004	3	2	+31.3
* 4.5	N	001	4	3	-23.9
* 3.9	O	003	4	4	+47.0
* 4.3	E	002	4	5	+12.5
* 4.5	D	006	3	4	- 3.3
* 8.3	B	010	5	5	+33.2
* 6.0	G	009	5	6	+40.9
* 6.1	J	007	4	2	-15.6
* 8.7	N	001	4	4	- 7.3
* 10.9	L	002	5	4	+ 5.0
* 8.3	K	008	2	5	44.9
* 8.3	J	007	4	3	-10.0
* 9.3	D	006	3	5	- .3
* 11.9	N	001	4	5	+ 9.8
* 10.3	J	007	4	4	- 1.0
* 11.3	I	007	5	4	+51.7
* 13.0	J	007	4	5	+ 2.8
* 13.4	H	005	5	5	+ 9.0
* 11.6	K	008	2	6	+54.7
* 12.6	D	006	3	6	+ 4.0
* 15.6	N	001	4	6	+21.3
* 14.5	E	002	4	6	+18.9
* 13.8	J	007	4	6	+13.5
* 17.1	H	005	5	6	+18.4
* 16.1	A	003	2	2	+32.8
* 17.3	L	002	5	5	+26.4
* 18.2	M	004	3	3	+42.0
* 18.0	R	001	3	2	+45.6
* 20.1	H	005	5	6	+18.4
* 19.0	A	003	2	3	+39.6
* 19.3	R	001	3	2	+45.6
* 19.5	L	002	5	6	+34.1
* 20.4	M	004	3	4	+51.5
* 21.8	I	007	5	5	+56.4

EVALUATION DATA TABLE

TABLE VII

Job #	Part #	Wkg. Days Date Due	A	$D_d - D_s$	B	time cpt.	Qty. cpt.
A	003	8	$ 42.42	10	$2596		
B	010	9	102.55	10	1703		
C	004	10	48.90	10	8674		
D	006	1	155.40	10	1857	12.5	3
E	002	3	62.82	10	7585	14.5	4
F	006	8	53.30	10	8482	.3	1
G	009	6	236.78	10	5099	6.0	5
H	005	4	92.85	10	3499	17.1	5
I	007	9	104.80	10	1030		
J	007	2	84.65	10	9235	13.8	4
K	008	7	34.18	10	6738	11.6	2
L	002	5	77.35	10	9458		
M	004	10	142.65	10	6990		
N	001	4	118.20	10	7767	15.6	4
O	003	7	22.00	10	3962		
P	001	12		10			
Q	002	12		10			
R	001	12		10			
S	010	12		10			

TABLE VIII

INITIAL SCHEDULE

JOB #	PART #	QUANTITY	DATE DUE	AT OPER#	STARTED AT	AVAIL. STATE #
A	003	2	8	1		01
B	010	5	9	3	- .6	05
C	004	1	10	4		01
D	006	3	1	2	- .8	01
E	002	4	3	4		05
F	006	1	8	5	- .4	03
G	009	5	6	4	- .5	04
H	005	5	4	3	- .7	02
I	007	5	9	3		04
J	007	4	2	1		01
K	008	2	7	4		05
L	002	5	5	3		01
M	004	3	10	1		03
N	001	4	4	2		01
O	003	1	7	3		03
P	001	2	12	1		04
Q	002	2	12	1		03
R	001	3	12	1		04
S	010	4	12	1		03
T	009	5	13	1		
U	005	3	13	1		
V	002	5	14	1		
W	008	1	14	1		
X	003	5	15	1		
Y	008	2	15	1		
Z	009	5	16	1		
AA	007	4	16	1		
AB	010	4	17	1		
AC	009	4	17	1		
AD	009	4	18	1		
AE	003	3	18	1		
AF	001	5	19	1		

Addit. Jobs →

An interesting measurement
Does not measure Scheduling efficiency?

BURT GRAD
㉒

Thoughts on "Manufacturing Cycle Efficiency"

Problem: To establish a measure of performance for Materials Management.

Criteria of measurement

a. Must be valid; i.e., must actually measure the Materials function, in whole or in part.

b. Must be interpretable into action; i.e., must provide a basis for subsequent improvement.

Definition of Manufacturing Cycle Efficiency *

a. Time basis--a comparison of the actual make time with the total elapsed time from start to finish, of a part, sub-assembly, final assembly or complete product assembly. $\frac{\Sigma W_i}{\Sigma T_i}$

b. Inventory investment basis--a comparison of the summarized individual make times, weighted by the value of each item, with the summarized total elapsed time, also weighted by the value of each item. $\frac{\Sigma W_i C_i}{\Sigma T_i C_i}$

These two definitions state clearly that the manufacturing cycle begins at the first operation of the chronological first part and ends at the final assembly operation (in some cases, packing is included).

Quite another definition is offered on page 4 of the Inventory Management book, dated March, 1950:

> "Define (Manufacturing cycle) as the time from the receipt of material until the time the product is shipped."

No differ

---

*Excerpt from Home Laundry Dept. --Production Control and Inventory Control Appraisal--November 1, 1955.

Well, What Is It?

Since definitions vary so widely, we must look to our criteria for help. What is the most valid measure and can it be interpreted easily for subsequent action? Here the narrow definition is weak. For example:

EXco company measures manufacturing cycle efficiency from first to last operation, or

$$\text{Eff } \% = \frac{\Sigma \text{ Operation Times}}{\Sigma \text{ Total Elapsed Times}} = \frac{100 \text{ hrs.}}{500 \text{ hrs.}} = 20\%$$

Suppose also that shop cost is divided as follows:

Raw Material	30%
WIP	50%
Finished Stock	20%

?

matl
labor
ovh

So what's wrong

We are thus measuring the "efficiency" of 50% of the materials responsibility for inventory investments. Now eXco plans to buy 40% of its present manufactured parts from specialty vendors. Assuming homogeneous operation hours / total hours, the efficiency remains the same 60/300 = 20%, but now manufacturing cycle efficiency accounts for only .6 x 50 or 30% of inventory dollars. Albeit an exaggerated example, the truth remains that the measurement base is constantly shifting. Also, the innate weight is far different for various businesses. In certain flow shops with short in-process time, the measurement is tied closely to the facilities plan and is almost entirely uncontrollable. In a long cycle job shop on the other hand, in-process inventory may be highly controllable, depending on the degree of perfection of the scheduling plan. Again, will this restricted definition of manufacturing cycle give us an important measure of materials efficiency over a broad range of departments?

What Should It Be?

Manufacturing cycle as related to the materials function encompasses far more than machine time. Responsibility for inventory dollars begins when material is received and ends when the product is shipped. This, then, should comprise the cycle, compounded of the following time spans:

1. Receipt to Inspection
2. Inspection to Storage
3. Storage to Machine
4. Machine to Packing
5. Packing to Storage
6. Storage to Shipping

Note that of these 6 spans only one--#4--fits the narrow description of manufacturing cycle. Note also that no matter what type of business--job or flow, product or process--the complete inventory responsibility time is included. The formula for manufacturing cycle efficiency, using the time spans 1 - 6 is:

$$\text{MCE \%} = \frac{\Sigma\ T_{04}\ \text{(operation times)}}{\Sigma(T_1 + T_2 + T_3 + T_4 + T_5 + T_6)}$$

This formula is concomitant with the first of our criteria. It recognizes the importance of total inventory responsibility time. It measures the materials job.

Something Missing?

Criterion B is still unsatisfied. The formula does not yet provide a sound basis for improvement. It is like an inaccurate set of scales, valid because weight is indicated, but useless because you are on the fence whether to gorge yourself or succumb to a starvation diet. Materials people are not generally measured by time per se, but rather by weighted time. So in order to grease the wheel that squeaks, we must factor in dollars of inventory. This merely means multiplying each time span by its average inventory value, as follows:

$$\frac{\Sigma(T_{04}\ C_{04})}{\Sigma(T_1 C_1 + T_2 C_2 \ldots + T_6 C_6)}$$ where C_{04} is the inventory investment of material on machines and C_1 - C_6 is the inventory investment of all material, ~~not in machines~~.

This results in a measure of efficiency of materials dollars--a measurement fully compatible, for purposes of comparison, with inventory turnover (also dollar weighted). There is thus a road to improvement, but not quite direct.

Don't Kill Time, Just Leave It Out

We have a formula, but still not as simple as it could be. In other words, why not leave time out entirely? Example:

The eXco Company measures manufacturing cycle efficiency by the weighted time method. Consider a single operation:

Operation time = 1 hour = T_0

Avg. WIP inventory value = \$10 = C_0

Pre-operation storage time = 1 hour = T

Pre-operation inventory value = \$5 = C

$$\text{MCE \%} = \frac{T_0 C_0}{T_0 C_0 + TC}$$

$$= \frac{1 \times 10}{(1 \times 10) + (1 \times 5)}$$

$$= 10/15 = 67\%$$

Note that 67% is the same efficiency obtained by dropping time from the equation:

$$\text{MCE\%} = \frac{C_0}{C_0 + C} = 10/15 = 67\%$$

Now let us double storage time:

$$\text{MCE \%} = \frac{1 \times 10}{(1 \times 10) + (2 \times 5)} = \frac{10}{20} = 50\%$$

By dropping time from the equation, we get:

$$\frac{10}{10 + 5} = 67\%$$

The first equation of 50% MCE would seem correct, since we have increased storage time and hence reduced efficiency. But the actual result is to give the formula a double weight. Here is why:

When eXco doubles storage time from . . .

storage | operation

to

storage | operation

. . . it must also double inventory dollars in storage, assuming a balance between storage and operation. This is axiomatic, since the operation still demands Y pieces per time period, yet storage time T is doubled. Therefore, the number of inventory dollars Z must double to maintain Y pieces in operations. The relationship is thus:

$$T_1 : T_2 = Z_1 : Z_2$$

T_1 = Time in hours before change

T_2 = Time in hours after change

Z_1 = Inventory dollars before change

Z_2 = Inventory dollars after change

Since the ratio exists in all near-equilibrium conditions, it is correct to leave out time. Otherwise we "double-weight" the MCE%. In the example above, equilibrium under the weighted time method would not be 50% but:

$$\frac{1 \times 10}{(1 \times 10) + (2 \times 10)} = \frac{10}{30} - 33\%$$

Under the dollar method, this is:

$$\frac{10}{10 + 10} = 10/20 \doteq 50\%$$

The latter is correct. Efficiency is not inordinately exaggerated as in the weighted time method.

The MCE formula is now:

$$\text{MCE} = \frac{E\ C_{04}}{E\ (C_1 + C_2 + C_3 + C_4 + C_5 + C_6)} \quad *$$

What's This About Equilibrium?

Equilibrium is a classical economist's term for "We know this is non-existent, but our textbooks can't have more than 500 pages." Equilibrium is the shorthand of economics, just as formulas are the shorthand of mathematics. It foreshortens an otherwise incomprehensible subject. In the context of manufacturing cycle efficiency, it is highly valid. What we want to measure is not the pile of steel waiting at the machine because Johnny Order Clerk pointed off the wrong decimal place, but rather the day-in, day-out paralysis of sub-standard materials performance. It must be assumed that Johnny's steel will be processed. The question is: What is it costing us? Equilibrium is not synonymous with efficiency, for a 5% MCE may reflect smoother material flow than one of 35%. However, it does allow us to observe the operation at a single point of time and interpolate meaningful data. This is the whole basis for dropping time from our equation, since it is a function of investment dollars, or vice-versa. While the day-to-day balance

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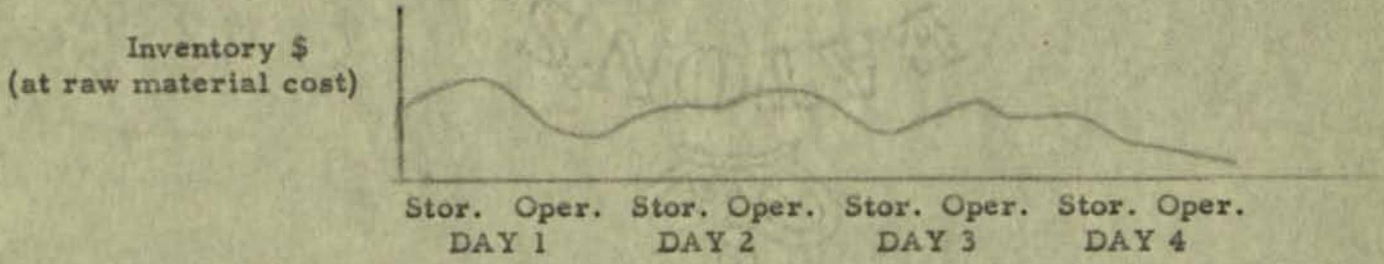
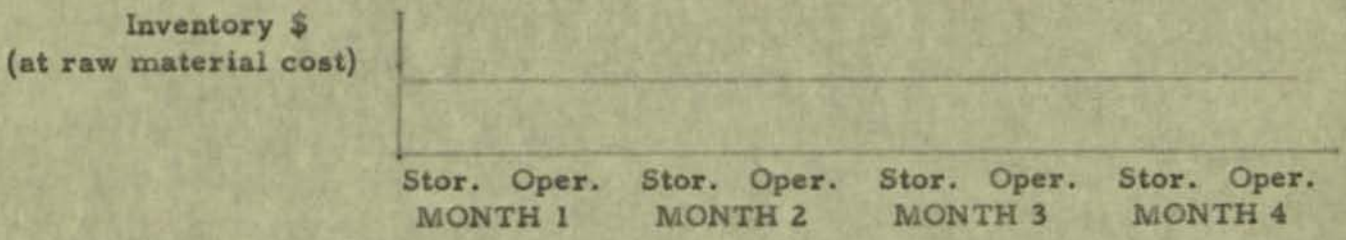
*The individual factors will admittedly differ, depending upon the number of time spans and their mathematical expression. However, the dollar concept still holds true.

between storage and operation may be . . .



. . . monthly, it would look like this:



This must be so, since operations are sustained by material and conversely, material must be operated upon.

Have We Forgotten Time?

In order to satisfy the second criterion, that of providing a built-in tool for improvement, it can be argued that we must consider time: shortening the cycle reduces inventory and improves customer service. Granted, but time is inherent in the formula, since it is a function of inventory dollars, and correlates closely with dollar weight.

Doubtless, MCE can be nothing more than a thermometer, indicating a malady. The cure must wait for diagnosis. Likewise, the inventory or scheduling specialist cannot reduce inventory or cycle time until he analyzes the elements that comprise MCE. Here a time cycle chart is invaluable. However, the omission of time from

MCE is not hereby invalidated, since MCE is only an indicator. Otherwise, as shown by the "double weight" argument, the indicator itself is faulty.

A Rose By Any Other Name

Now for the matter of terminology. True, MCE has been described by word and formula. However, the raft of definitions for manufacturing cycle will perforce cause misinterpretation. Better to tailor the name to the circumstances than vice-versa, and we're talking now of inventory cycle, the span(s) of time during which the materials function holds responsibility for inventory dollars. A better term, then, is Inventory Cycle Efficiency, of which the manufacturing cycle is only one segment.

Measuring ICE

Inventory Cycle Efficiency can now be measured easily, continuously, without the need for time studies,* work sampling* or the like. The dollar value of material being worked upon is divided by the dollar value of all other material: in storage, in transit or float, in finished stock, and so on. The formula:

$$ICE = \frac{\Sigma C_0}{\Sigma C}$$

where C_0 is the cost of inventory on machines or otherwise being processed or fabricated and C is the total cost of all inventory.

Quo Vadis, Customer Service?

It may be argued (anticipating some argument, eh what?) that ICE dilutes the weight given customer service since service is dependent, for the most part, on

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*These techniques, however, are used in the second, or improvement, stage.

the manufacturing cycle per se (from first machine through last machine.) This is admittedly true, but the importance of including total materials responsibility precludes the more restricted formula. However, and this is most important, ICE is not the last word. A ratio of operations dollars to total in-process dollars would be necessary to isolate bottlenecks in the manufacturing time cycle. As a vital corollary of ICE, then, a second formula for In-process Inventory Cycle Efficiency follows:

$$\text{In-process ICE} = \frac{E\ C_0}{E\ C_{IP}}$$

where C_0 is the cost of inventory on machines or otherwise being processed or fabricated and C_{IP} is the total cost of all inventory in-process (from first operation through last operation).

ICE Related to Inventory Turnover

There is a logical relationship here. An inventory turnover of 12 means 1 month of inventory dollars to cost of sales on hand. An ICE of 10% says that of this one month's inventory, only 10% is being enhanced in value through manufacturing. An In-process ICE of 30% further describes the actual period during which value is added. It says that out of 10 inventory dollars in-process, only 3 are efficient; i.e., are being worked upon. The remaining 7 are in abeyance and are actual or potential deterrents to customer service.

Writer's Cramp

Inventory Cycle Efficiency and its logical offspring can be soliloquized ad infinitum and perhaps beyond, but because this script is already protracted beyond the normal readable length (there must be a formula for this), I shall cease fire and await the return volley.

R. P. O'Brien

5/31/56

additional projects.

~~Protective stock determination~~

~~Usage prediction~~

~~Production scheduling~~

~~Make or Buy decision~~

~~Reorder point determination~~

Return on Investment determination

Use of mechanization, electronics + OR in Inv Cont.

~~Cost of processing an order~~

~~Economical order quantity~~

~~Cost of Carrying Inventory~~

Computer future lies in departmental integration of data processing function –

why use IBM equip in Flow type shops

- ABC – finish write up on how to do it.
- Receiving Routines
- Use of E.O.Q. – ala Chap II of Inv mgt man
- Cost of Running out of Inventory.

Optimum Scheduling
using Linear Programming

Chemical

Paint making

a good easy sched. prob.

Electronically —

40 mills —
could probably test all permutations .

mix off decision

Turnover analysis

Develop true IME. + PECE, etc

Input curves.

→ Analyze why T/O should exclude AAE –

• In calc Cost of Carrying Inv would this make any difference

• How about Employee pay lag.

→ set up method for computing planned Turnover.

Turnover Computation

①

are they making an error in calculating

T/O - new way.

$$TO_i = \frac{\left(SCO_{i+1} + SCO_{i+2} + SCO_{i+3}\right)\frac{WD_y}{WD_{i+1} + WD_{i+2}\,WD_{i+3}}}{I_i}$$

SCO = Shop Cost Output

WD = wkg days

I = Inventory

i, i+1, etc refers to month no.

subscript calendar.
y = year

$$TO_y = \sum_{i=1}^{12} TO_i$$

$$TO_y = \frac{\left(SCO_2 + SCO_3 + SCO_4\right)\frac{WD_y}{WD_2 + WD_3 + WD_4}}{I_1} + \frac{\left(SCO_3 + SCO_4 + SCO_5\right)\frac{WD_y}{WD_3 + WD_4 + WD_5}}{I_2} + \dots + \frac{\left(SCO_{13} + SCO_{14} + SCO_{15}\right)\frac{WD_y}{WD_{13} + WD_{14} + WD_{15}}}{I_{12}}$$

$$TO_y = \frac{WD_y\,SCO_2 + WD_y\,SCO_3 + WD_y\,SCO_4}{I_1 WD_2 + I_1 WD_3 + I_1 WD_4} + \frac{WD_y\,SCO_3 + WD_y\,SCO_4 + WD_y\,SCO_5}{I_2 WD_3 + I_2 WD_4 + I_2 WD_5} + \dots + \frac{WD_y\,SCO_{13} + WD_y\,SCO_{14} + WD_y\,SCO_{15}}{I_{12} WD_{13} + I_{12} WD_{14} + I_{12} WD_{15}}$$

②

if assume $I_1 = I_2 = \ldots = I_{12} = I_i$

$$TO_4 = \frac{WD_4}{I_i} \quad \frac{(SCO_2 + SCO_3 + SCO_4)(Den - WD_2 - WD_3 - WD_4) + \ldots}{WD_2 + 2WD_3 + 3WD_4 + 3WD_5 + \ldots + 3WD_{13} + 2WD_{14} + WD_{15}}$$

$$Den = WD_2 + 2WD_3 + \ldots + WD_{15}$$

$$Den = 3WD_4 + 3WD_{13} + 2WD_{14} + WD_{15} - WD_3 - 2WD_2 - 3WD_1$$

$$num = (SCO_2 + SCO_3 + SCO_4)(Den - WD_2 - WD_3 - WD_4) + \ldots +$$
$$(SCO_{13} + SCO_{14} + SCO_{15})(Den - WD_{13} - WD_{14} - WD_{15})$$

if $SCO_i = CWD_i$ where C is a Constant

then

$$num = (CWD_2 + CWD_3 + CWD_4)(Den - WD_2 - WD_3 - WD_4)$$
$$+ \ldots + (CWD_{13} + CWD_{14} + CWD_{15})(Den - WD_{13} - WD_{14} - WD_{15})$$

$$num = C\Big\{\left[Den(WD_2 + WD_3 + WD_4) - (WD_2 + WD_3 + WD_4)^2\right]$$
$$+ \ldots + C\left[Den(WD_{13} + WD_{14} + WD_{15}) - (WD_{13} + WD_{14} + WD_{15})^2\right]\Big\}$$

let $A_i = WD_{i+1} + WD_{i+2} + WD_{i+3}$

then

$$\text{Accm} = C\left\{\left[\text{Den}(A_1) - A_1^2\right] + \ldots + \left[\text{Den}(A_{12}) - A_{12}^2\right]\right\}$$

and $1 \leq A_i \ll \text{Den}$

now if $A_6 < A_1$

$$\text{Den}(A_1) - A_1^2 > \text{Den}(A_6) - A_6^2$$

True Turnover for the year by present technique

$$TO_y = \frac{12}{36}\,\frac{(SCO_2 + 2SCO_3 + 3SCO_4 + \ldots + 3SCO_{13} + 2SCO_{14} + SCO_{15})}{\sum_{i=1}^{12} I_i}$$

or

$$TO_y = \frac{SCO_2 + 2SCO_3 + 2SCO_{14} + SCO_{15} + 3\sum_{i=4}^{13} SCO_i}{3\sum_{i=1}^{12} I_i}$$

The WD technique should yield this answer.

~~Pro~~

Product Explosion

Ordering process

2 sources to start out process
Customer's order
Schedule of wants

must specify:
{ Model no.
Qty
Date to be completed

from this we must determine gross parts requirements by exploding the model into its parts.

You perform 2 steps

- multiply qty by qty of part/next level up
- Subtract assy lead time from assy due complete date to get parts due complete date.

This procedure can be { Single level
Component level
multiple level

also can be performed by synthesis - working from a where-used file

Result is: pt no
Qty
date needed complete.

Parts break down into these essential characters:

TO NEED VS TO STOCK

PURCH VS MFD

any "to stock" part introduces a cushion between need and order — this results in the order qty, dates being different in the purchased part

But this is even more significant in the mfd items, where "raw material" - anything that has further operations performed to it other than assembly -

~~is not~~ is not directly proportional to parts needs, but rather to stock order needs.

We must then decide whether we are operating a continuous explosion plan or do-it-once-every-month-or-so plan.

First step regardless is to arrange need cards by part identification number and due complete date; maybe (unless they were already that way from a synthesis type explosion –

Pass these cards against a master stock file (If you are preassigning this can actually be the stock balance master file). [illegible] This will select the stock items and put them in a separate stack, leaving the non-stock (to need) items.

Each "to need" item is taken to the material and operation file & has removed from file the deck for that item. By reproducing this in an IBM 528 multiple output cards can be obtained. The first card is the RM card & after reproduction one of the corresponding work cards is extended and the resultant cards matched against a Raw material stock deck. If the item is not stock the card becomes a "to need" card, purchased and goes to Purchasing. If it is stores it is ~~grouped and~~ held for later preassignment processing.

The stores parts are run thru a stock control process and where on hand + on order qtys fall below the reorder pt. a new order needed card is prepared. This then follows the same routine as a "to need" card

Finally the RM cards are processed thru a special stores analysis routine and necessary order cards go to Purchasing.

→ Explosion all the way to RM need can only be combined for non-stores parts or if all stores is preassigned + stores coverage never exceeds scheduled commitments.