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CURVE FITTING WITH ALLOWANCE FOR ERRORS
IN GIVEN DATA

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CURVE FITTING WITH ALLOWANCE FOR

ERRORS IN GIVEN DATA.

The method of curve fitting described in this report is intended to produce a smooth curve, which does not necessarily pass thru all the given points. Since in general the given points will be experimentally determined, their positions are subject to experimental error. To insist that the curve passes exactly thru all the points will involve a sacrifice of smoothness. On the other hand, there is no harm in allowing the curve to deviate from some or all the points, provided that these deviations are kept within the limits of experimental error. The present method allows the operator to find the most desirable compromise between the accuracy of fit and the smoothness of the curve obtained.

Measure of fit.

We assume that the given points are specified by giving their coordinates $P_1 = (x_1, Y_1)$, $P_2 = (x_2, Y_2), \ldots P_n (x_n, Y_n)$; n being the number of points. Here it is assumed that $x_1 < x_2 < x_3 < \ldots < x_n$, so that no two values of Y correspond to the same x. If the data include two or more different values of Y for the same x, an average of these values is assumed to be used as the value of Y.

Standard deviation, σ, of Y's from the curve is assumed to be the measure of goodness of fit. It is the positive square root of

$$\sigma^2 = \frac{1}{n} \sum_{k=1}^{n} (y_k - Y_k)^2, \qquad (1)$$

where y_k is the value of

$$y = f(x) \qquad (2)$$

for $x = x_k$; Eq. (2) being the equation of the curve.

Measure of curviness

Many different measures of curviness may be used. A theoretically ideal measure might be

$$S = \int_{x_1}^{x_n} K^2 ds \bigg/ \int_{x_1}^{x_n} ds, \qquad (3)$$

where

$$K(x) = \frac{y''}{\left[1 + (y')^2\right]^{3/2}} \qquad (4)$$

is the curvature. Eq. (3) gives the average of the square of the curvature per unit length of the curve, $ds = \left[1 + (y')^2\right]^{\frac{1}{2}} dx$ being an element of length of the curve. However, an attempt to use Eq. (3) leads to hopelessly complicated equations. The squaring of K is necessary, for otherwise large positive and negative K's may combine to give a small value of S for a curve that is far from being smooth.

To avoid complication we choose

$$S = \int_{x_1}^{x_n} (y'')^2 dx \qquad (5)$$

as our measure of curviness. If y' is considerably smaller that 1; the S defined by (5) will approximately equal (3), except for a constant factor $x_n - x_1$, which has no effect on what follows. However, even when y' is large, a small value of S of Eq.(5) will ensure that y'' is small, and that therefore y' is nearly constant, so that $y = f(x)$ approximates a straight line.

Combined Requirements
Eqs. (1) and (5) give two quantities that we wish to be small. However, we cannot minimize both of them, since making one smaller generally makes the other larger, and conversely.

The best we can do is to assume some constant value for one, and then make the other as small as possible. It turns out that it makes no difference which is kept constant and which is allowed to vary, the results are the same in both cases. This can be seen as follows:

Suppose that the curve is given a small variation from its optimum shape, so that instead of Eq. (2) it is now given by

$$y = f(x) + \varepsilon \eta(x), \qquad (6)$$

where ε is very small and $\eta(x)$ is arbitrary. This produces a change in y equal to

$$\delta y = \varepsilon \eta(x), \qquad (7)$$

which causes the changes $\delta (\sigma^2)$ and δ S. One of them
has to be zero because the varied quantity is assumed to be
constant, the other variation is zero because the varied quantity
is to be a minimum. Thus, whether σ^2 or S is kept constant,
we must have $\delta \sigma^2 = 0$ **and** δ S = 0 for an arbitrary small variation
δ y.

Now

$$n \, \delta \sigma^2 = 2 \sum_{k=1}^{n} (y_k - Y_k) \delta y_k = 2 \varepsilon \sum_{k=1}^{n} (y_k - Y_k) \eta (x_k),$$

and

$$\delta S = 2 \int_{x_1}^{x_n} y'' \delta y'' \, dx = 2\varepsilon \int_{x_1}^{x_n} y'' \eta'' \, dx;$$

so that our conditions become

$$\sum_{k=1}^{n} (y_k - Y_k) \eta(x_k) = 0 \qquad (8)$$

and

$$\int_{x_1}^{x_n} y''(x) \, \eta''(x) \, dx = 0 \qquad (9)$$

Eqs. (8) and (9) have to hold for arbitrary $\eta(x)$, assumed
to be doubly differentiable.

Mathematical transformations.

As they stand Eqs. (8) and (9) are not convenient. We therefore
transform them as follows: Eq. (8) can be written in the form

$$\lim_{\mu \to 0} \int_{x_1 - \mu}^{x_n + \mu} \left\{ \sum_{k=1}^{n} \left[y(x) - Y_k \right] \delta (x - x_k) \right\} \eta(x) dx = 0, \quad (10)$$

where $\delta (x - x_k)$ is Dirac's delta function, and μ is an arbitrary
positive quantity.

Eq. (9) can be written with the same limits of integration as
Eq. (10). Then, integrating by parts twice we obtain:

$$\lim_{\mu \to 0} \left\{ \left[y''(x) \eta'(x) - y'''(x) \eta(x) \right]_{x_1 - \mu}^{x_n + \mu} + \int_{x_1 - \mu}^{x_n + \mu} y''''(x) \eta(x) dx \right\} = 0 \quad (11)$$

Since $\eta'(x)$ is arbitrary, this requires that $y''(x) = 0$ at
both end points; i.e.,

$$y''(x_1) = 0 \text{ and } y''(x_n) = 0 \qquad (12)$$

The term $\lim\limits_{\mu \to 0} \left[- y'''(x)\, \eta(x) \right]_{x_1 - \mu}^{x_n + \mu}$ can be represented by

$$\lim_{\mu \to 0} \int_{x_1 - \mu}^{x_n + \mu} \left[y'''(x) \quad \left[\delta (x - x_1) - \delta (x - x_n) \right] \eta(x) \, dx. \right. \tag{13}$$

With Eqs. (12) assumed to hold, Eq. (11) now becomes:

$$\lim_{\mu \to 0} \int_{x_1 - \mu}^{x_n + \mu} \left[y'''' y'''(x) \delta (x - x_1) - y'''(x) \delta (x - x_n) \right] \eta(x) \, dx = 0 \tag{14}$$

Eqs. (10) and (14) are now to be combined. If we had Eq. (14) alone, we would, since $\eta(x)$ would then be arbitrary, require that the bracketed expression in the integrand be zero. But $\eta(x)$ cannot be completely arbitrary, since it must be such as to satisfy Eq. (10), which in this case must be regarded as a condition on $\eta(x)$. Conversely, the coefficient of $\eta(x)$ in Eq. (10) cannot be set equal to zero, for then Eq. (14) would not be satisfied. As usual, we shall use the method of Lagrangian multipliers. This consists in our case in multiplying one of the two equations, either Eq. (10) or Eq. (14), by an undetermined parameter, and adding to the other. We choose the second procedure, and obtain:

$$\lim_{\mu \to 0} \int_{x_1 - \mu}^{x_n + \mu} \left\{ \sum_{k=1}^{n} \left[y(x) - Y_k \right] \delta (x - x_k) + \lambda\, y'''' + \lambda y''' \left[\delta (x - x_1) \right. \right.$$
$$\left. \left. - \delta (x - x_n) \right] \right\} \eta(x) \, dx = 0 \tag{15}$$

The value of this method consists in the fact that now $\eta(x)$ can be treated as arbitrary, and we must have the following equation holding:

$$\lambda y'''' + \lambda\, y''' \left[\delta (x - x_1) - \delta (x - x_n) \right] + \sum_{k=1}^{n} \left[y(x) - Y_k \right] \delta (x - x_k) = 0 \tag{16}$$

Remarks on the meaning of λ

As we have seen, the solution of Eqs. (12) and (16), subject to whatever further conditions we wish to impose, may be regarded either as the solution minimizing δ^2 with given S (see Eqs. (1) and (5)), or as minimizing S with given δ^2. We choose the second interpretation. The solution of Eq. (16) will contain λ as a parameter. The solution can then be substituted into Eq. (1), and solved for λ (δ^2 being given).

It can be shown that, for small λ, σ is directly proportional to λ. This can be made the basis of determining suitable λ by an iteration procedure.

Another way of interpreting λ consists of regarding it as the relative weight to be given the equation $\int S = 0$, compared with the equation $\delta \int = 0$, the latter being assigned the unit weight. For $\lambda = 0$, the curve must pass through all the given points; for $\lambda = \infty$, the curve becomes one straight line.

Discussion of Eq. (16).

Multiplying Eq. (16) by dx and integrating from $x = x_1 - \varepsilon$ to $x = x_m + \xi$, with $0 < \xi < (x_{m+1} - x_m)$, we obtain, in the limit as $\varepsilon \to 0$,

$$\lambda y'''(x_m + \xi) + \sum_{k=1}^{m} \left[y(x_k) - Y_k \right] = 0 \tag{17}$$

This is obtained with the help of the equation

$$\int_{x_k - a}^{x_k + b} F(x) \delta(x - x_k)\, dx = F(x_k) \tag{18}$$

which is a property of the Dirac delta function $\delta(x - x_k)$ and holds for any $F(x)$ with arbitrary positive a and b.

Eq. (17) shows that in general y''' changes suddenly as x passes thru one of the given values, x_k, but remains constant between two consecutive values of x.

Therefore the required curve consists of a set of cubic parabolas, one for each interval between given values of x, which we shall take to be of the form

$$y(x) = a_m + b_m x + c_m x^2 + d_m x^3 \tag{19}$$

for the m - th interval, defined by

$$x_m \leq x \leq x_{m+1}, \quad 1 \leq m \leq n - 1. \tag{20}$$

Continuity

The possibility of equalities in the relation (20) means that we

assume $y(x)$ to be continuous at points x_m. In fact, at this point, by Eq. (19), for $x = x_m$,

$$y(x_m) = a_m + b_m\, x_m + c_m\, x_m^2 + d_m\, x_m^3$$

On the other hand, replacing m by m - 1 in Eq. (19) and then taking $x = x_m$,

$$y(x_m) = a_{m-1} + b_{m-1}\, x_m + c_{m-1}\, x_m^2 + d_{m-1}\, x_m^3$$

so that we must have

$$a_m + b_m\, x_m + c_m\, x_m^2 + d_m\, x_m^3 = a_{m-1} + b_{m-1}\, x_m$$
$$+ c_{m-1}\, x_m^2 + d_{m-1}\, x_m^3, \quad (21)$$

which is the condition of continuity of $y(x)$ at the point x_m. This must hold for $m = 2, 3, \ldots (n-1)$, thus providing us with $n - 2$ equations connecting $4(n-1)$ constants $a_1, b_1, c_1, d_1, a_2, \ldots d_{n-1}$.

We may, and do, require also continuity for y' and y''. This gives us additional $2(n-2)$ equations:

$$b_m + 2\, c_m\, x_m + 3\, d_m\, x_m^2 = b_{m-1} + 2\, c_{m-1}\, x_m + 3 d_{m-1}\, x_m^2 \quad (22)$$

and

$$c_m + 3\, d_m\, x_m = c_{m-1} + 3\, d_{m-1}\, x_m \quad (23)$$

both holding for $m = 2, 3, \ldots (n-1)$

Eq. (23) is a simple recursion formula
$$c_m - c_{m-1} = 3\, (d_{m-1} - d_m)\, x_m, \quad (24)$$

which can be solved for c_m, $m > 1$, in terms of c_1 and the d's. Thus, writing down the set of equations obtainable from Eq. (24) by letting $m = 2, 3, \ldots k$, and adding them together, we get:

$$c_k - c_1 = 3 \sum_{m=2}^{k} (d_{m-1} - d_m)\, x_m, \quad k = 2, 3, \ldots (n-1). \quad (25)$$

Multiplying Eq. (23) by $2 x_m$ and subtracting from Eq. (22) we obtain,

$$b_m - b_{m-1} = -3\, (d_{m-1} - d_m)\, x_m^2,$$

which is analogous to Eq. (24), and gives

$$b_k - b_1 = -3\sum_{m=2}^{k} (d_{m-1} - d_m) x_m^2, \quad k = 2, 3, \ldots(n-1). \qquad (26)$$

In a similar way, multiplying Eq. (22) by x_m and subtracting from Eq. (21), we get

$$a_m - c_m x_m^2 - 2d_m x_m^2 = a_{m-1} - c_{m-1} x_m^2 - 2d_{m-1} x_m^2$$

Further, multiplying Eq. (23) by x_m^2 and adding to the last equation above, there results

$$a_m - a_{m-1} = (d_{m-1} - d_m) x_m^3,$$

which is solved anologously to Eq. (24), giving

$$a_k - a_1 = \sum_{m=2}^{k} (d_{m-1} - d_m) x_m^3, \quad k = 2, 3, \ldots(n-1). \qquad (27)$$

Eqs. (25), (26) and (27) give $3(n-2)$ constants in terms of the remaining $n + 2$, namely a_1, b_1, c_1, d_1, $d_2, \ldots d_{n-1}$

Modified variational problem

The quantities σ^2 of Eq. (1) and S of Eq. (5) can now be made more specific by expressing them in terms of the last named $n + 2$ variables. Thus, since

$$y''(x_m + \xi) = 2\left[c_m + 3d_m (x_m + \xi)\right]$$

$$S = 4 \sum_{m=1}^{n-1} \int_{x_m}^{x_{m+1}} \left[c_m + 3d_m x\right]^2 dx$$

$$= 4 \sum_{m=1}^{n-1} \left[(x_{m+1} - x_m) c_m^2 + 3(x_{m+1}^2 - x_m^2) c_m d_m + 3(x_{m+1}^3 - x_m^3)d_m^2\right]$$

The equation $\delta S = 0$, can now be replaced by

$$\sum_{m=1}^{n-1} \left\{ \left[2(x_{m+1} - x_m) c_m + 3 (x_{m+1}^2 - x_m^2)d_m\right]\delta c_m \right.$$

$$\left. + \left[3(x_{m+1}^2 - x_m^2) c_m + 6(x_{m+1}^3 - x_m^3) d_m\right]\delta d_m \right\} = 0$$

using Eq. (25), we now replace c_m and δc_m $(m > 1)$ by $c_1, \delta c_1$, the d's and their variations. The calculation is rather lengthy, and the result is:

$$R \delta c_1 + P_1 \delta d_1 + \sum_{k=2}^{n-1} P_k \delta d_k = 0 \qquad (28)$$

where

$$R = 2(x_n - x_1) c_1 + 3 (2x_2 x_n - x_1^2 - x_2^2) d_1 + 3 \sum_{m=2}^{n-1} (x_{m+1} - x_m) \cdot$$

$$(2x_n - x_m - x_{m+1}) d_m$$

$$P_1 = 3(2x_2 x_n - x_1^2 - x_2^2) c_1 + 6(3x_2^2 x_n - x_1^3 - 2x_2^3) d_1$$

$$+ 9x_2 \sum_{m=2}^{n=1} (x_{m+1} - x_m)(2x_n - x_m - x_{m+1}) d_m$$

$$P_k = 3(x_{k+1} - x_k)(2x_n - x_k - x_{k+1}) c_1 + 9x_2 (x_{k+1} - x_k)(2x_n - x_k - x_{k+1}) d_1$$

$$+ 9(x_{k+1} - x_k)(2x_n - x_k - x_{k+1}) \sum_{m=2}^{k-1} (x_{m+1} - x_m) d_m$$

$$6 (x_{k+1} - x_k)^2 (3x_n - x_k - 2x_{k+1}) d_k$$

$$+ 9 (x_{k+1} - x_k) \sum_{m=k+1}^{n-1} (x_{m+1} - x_m)(2x_n - x_m - x_{m+1}) d_m, \quad 2 \le k \le n-1$$

Similarly, using Eq. (19), Eq. (1) becomes

$$n \sigma^2 = \sum_{k=1}^{n-1} (a_k + b_k x_{k+1} + c_k x_{k+1}^2 + d_k x_{k+1}^3 - Y_{k+1})^2$$

$$+ (a_1 + b_1 x_1 + c_1 x_1^2 + d_1 x_1^3 - Y_1)^2 \quad (29)$$

With the help of Eqs. (25), (26), and (27), the equation $\delta \sigma^2 = 0$, becomes

$$L \delta a_1 + M \delta b_1 + N \delta c_1 + \sum_{p=1}^{n-1} Q_p \delta d_p = 0 \quad (30)$$

where

$$L = n a_1 + b_1 \sum_1^n x_k + c_1 \sum_1^n x_k^2$$

$$+ d_1 \left\{ \sum_2^n \left[x_k^3 - (x_k - x_2)^3 \right] + x_1^3 \right\}$$

$$+ \sum_{m=2}^{n-1} d_M \sum_{k=m+1}^{N} \left[(x_k - x_m)^3 - (x_k - x_{m+1})^3 \right] - \sum_{1} Y_k$$

$$M = a_1 \sum_{1}^{n} x_k + b_1 \sum_{1}^{n} x_k^2 + c_1 \sum_{1}^{n} x_k^3$$

$$+ d_1 \left\{ \sum_{2}^{n} x_k \left[x_k^3 - (x_k - x_2)^3 \right] + x_1^4 \right\} + \sum_{m=2}^{n-1} d_m \sum_{\ell=m+1}^{n} x_k \cdot$$

$$\left[(x_k - x_m)^3 - (x_k - x_{m+1})^3 \right] - \sum_{1} x_k Y_k$$

$$N = a_1 \sum_{1}^{n} x_k^2 + b_1 \sum_{1}^{n} x_k^3 + c_1 \sum_{1}^{n} x_k^4$$

$$+ d_1 \left\{ \sum_{2}^{n} x_k^2 \left[x_k^3 - (x_k - x_2)^3 \right] + x_1^5 \right\}$$

$$+ \sum_{m=2}^{n-1} d_m \sum_{k=m+1}^{n} x_k^2 \left[(x_k - x_m)^3 - (x_k - x_{m+1})^3 \right] - \sum_{1}^{n} x_k^2 Y_k$$

$$Q_1 = a_1 \left\{ \sum_{2}^{n} \left[x_k^3 - (x_k - x_2)^3 \right] + x_1^3 \right\} + b_1 \left\{ \sum_{2}^{n} x_k \cdot \right.$$

$$\left. \left[x_k^3 - (x_k - x_2)^3 \right] + x_1^4 \right\}$$

$$+ c_1 \left\{ \sum_{2}^{n} x_k^2 \left[x_k^3 - (x_k - x_2)^3 \right] + x_1^5 \right\}$$

$$+ d_1 \left\{ \sum_{2}^{n} \left[x_k^3 - (x_k - x_1)^3 \right]^2 + x_1^6 \right\}$$

$$+ \sum_{m=2}^{n-1} d_m \left\{ \sum_{k=m+1}^{n} \left[x_k^3 - (x_k - x_2)^3 \right] \left[(x_k - x_m)^3 - (x_k - x_{m+1})^3 \right] \right.$$

$$\left. - x_1^3 Y_1 + \sum_{2}^{n} \left[x_k^3 - (x_k - x_2)^3 \right] Y_k \right.$$

$$Q_p \ (2 \leq p \leq n-1) = a_1 \sum_{k=p+1}^{n} \left[(x_k - x_p)^3 - (x_k - x_{p+1})^3 \right] + b_1 \sum_{k=p+1}^{n} x_k \cdot$$

$$\left[(x_k - x_p)^3 - (x_k - x_{p+1})^3 \right]$$

$$+ c_1 \sum_{k=p+1}^{n} x_k^2 \left[(x_k - x_p)^3 - (x_k - x_{p+1})^3 \right] + d_1 \sum_{k=p+1}^{n} \left[x_k^3 - (x_k - x_2)^3 \right] \cdot$$

$$\left[(x_k - x_p)^3 - (x_k - x_{p+1})^3 \right]$$

$$+ \sum_{m=2}^{p-1} d_m \sum_{k=p+1}^{n} \left[(x_k - x_m)^3 - (x_k - x_{m+1})^3 \right] \left[(x_k - x_p)^3 - (x_k - x_{p+1})^3 \right]$$

$$+ d_p \sum_{k=p+1}^{n} \left[(x_k - x_p)^3 - (x_k - x_{p+1})^3 \right]^2$$

$$+ \sum_{m=p+1}^{n-1} d_m \sum_{k=m+1}^{n} \left[(x_k - x_m)^3 - (x_k - x_{m+1})^3 \right] \cdot \left[(x_k - x_p)^3 \right.$$

$$\left. - (x_k - x_{p+1})^3 \right] - \sum_{k=p+1}^{n} \left[(x_k - x_p)^3 - (x_k - x_{p+1})^3 \right] Y_k$$

Eq. (28) is now multiplied by λ and added to Eq. (30). Then $\delta a_1, \delta b_1, \delta c_1, \delta d_1, \ldots \delta d_{n-1}$ are treated as arbitrary independent quantities, so that their coefficients can be set equal to zeros. We then obtain the set of equations:

$$L = 0, \tag{31}$$

$$M = 0, \tag{32}$$

$$N + \lambda R = 0, \tag{33}$$

$$Q_p + \lambda P_p = 0, \quad 1 \leq p \leq n - 1. \tag{34}$$

Eq. (34) is really n - 1 equations, one for each value of p. We thus have n + 2 equations for the n + 2 unknowns, a_1, b_1, c_1, $d_1, \ldots d_{n-1}$.

<u>Simplification</u>

Examination of our equations shows that considerable simplification

can be achieved if $x_1 = 0$; i. e., if the first point corresponds to $x = 0$. However, since in general this will not be the case, we can achieve the same result by the transformation

$$\overline{X} = x - x_1 \tag{35}$$

and the use of the new independent variable $\overline{X}$ instead of x. Instead of Eq. (19) we would then use

$$y(\overline{X}) = A_k + B_k \overline{X} + C_k \overline{X}^2 + D_k \overline{X}^3 \tag{36}$$

If desired, the old coefficients $a_k, \ldots d_k$ can then be found by equating the right sides of Eqs. (19) and (36) and using Eq. (35).

Equations (25) to (34) remain valid if we now replace x by $\overline{X}$, a by A, b by B, etc. and put $\overline{X}_1 = 0$. It now becomes possible to write the expressions for R, P_k, L, M, N, Q_k in a more compact form.

Thus, we now have:

$$R = 2\overline{X}_n C_1 + 3\sum_{m=1}^{n-1}(\overline{X}_{m+1} - \overline{X}_m)(2\overline{X}_n - \overline{X}_m - \overline{X}_{m+1})D_m \tag{37}$$

$$P_p = 3(\overline{X}_{p+1} - \overline{X}_p)(2\overline{X}_n - \overline{X}_p - \overline{X}_{p+1})C_1$$

$$+ 9(\overline{X}_{p+1} - \overline{X}_p)(2\overline{X}_n - \overline{X}_p - \overline{X}_{p+1})\sum_{m=1}^{p-1}(\overline{X}_{m+1} - \overline{X}_m)D_m$$

$$+ 6(\overline{X}_{p+1} - \overline{X}_p)^2 (3\overline{X}_n - \overline{X}_p - 2\overline{X}_{p+1})D_p$$

$$+ 9(\overline{X}_{p+1} - \overline{X}_p)\sum_{m=p+1}^{n-1}(\overline{X}_{m+1} - \overline{X}_m)(2\overline{X}_n - \overline{X}_m - \overline{X}_{m+1})D_m \tag{38}$$

for $1 \leq p \leq n - 1$.

$$L = nA_1 + B_1\sum_2 \overline{X}_k + C_1\sum_2 \overline{X}_k^2$$

$$+ \sum_{m=1}^{n-1} D_m \sum_{k=m+1}\left[(\overline{X}_k - \overline{X}_m)^3 - (\overline{X}_k - \overline{X}_{m+1})^3\right] - \sum_1 Y_k \tag{39}$$

$$M = A_1 \sum_2 \overline{X}_k + B_1 \sum_2 \overline{X}_k^2 + C_1 \sum_2 \overline{X}_k^3$$

$$+ \sum_{m=1}^{n-1} D_m \sum_{k=m+1}^{n} \bar{X}_k \left[(\bar{X}_k - \bar{X}_m)^3 - (\bar{X}_k - \bar{X}_{m+1})^3 \right]$$

$$- \sum_{2}^{n} \bar{X}_k Y_k \qquad (40)$$

$$N = A_1 \sum_{2}^{n} \bar{X}_k^2 + B_1 \sum_{2}^{n} \bar{X}_k^3 + C_1 \sum_{2}^{n} \bar{X}_k^4$$

$$+ \sum_{m=1}^{n-1} D_m \sum_{k=m+1}^{n} \bar{X}_k^2 \left[(\bar{X}_k - \bar{X}_m)^3 - (\bar{X}_k - \bar{X}_{m+1})^3 \right] - \sum_{2}^{n} \bar{X}_k^2 Y_k \qquad (41)$$

$$Q_p = A_1 \sum_{k=p+1}^{n} \left[(\bar{X}_k - \bar{X}_p)^3 - (\bar{X}_k - \bar{X}_{p+1})^3 \right] + B_1 \sum_{k=p+1}^{n} \bar{X}_k \left[(\bar{X}_k - \bar{X}_p)^3 \right.$$

$$\left. - (\bar{X}_k - \bar{X}_{p+1})^3 \right]$$

$$+ C_1 \sum_{k=p+1}^{n} \bar{X}_k^2 \left[(\bar{X}_k - \bar{X}_p)^3 - (\bar{X}_k - \bar{X}_{p+1})^3 \right]$$

$$+ \sum_{m=1}^{p} D_m \sum_{k=p+1}^{n} \left[(\bar{X}_k - \bar{X}_m)^3 - (\bar{X}_k - \bar{X}_{m+1})^3 \right] \left[(\bar{X}_k - \bar{X}_p)^3 - (\bar{X}_k - \bar{X}_{p+1})^3 \right]$$

$$+ \sum_{m=p+1}^{n-1} D_m \sum_{k=m+1}^{n} \left[(\bar{X}_k - \bar{X}_m)^3 - (\bar{X}_k - \bar{X}_{m+1})^3 \right] \left[(\bar{X}_k - \bar{X}_p)^3 \right.$$

$$\left. - (\bar{X}_k - \bar{X}_{p+1})^3 \right]$$

$$- \sum_{k=p+1}^{n} \left[(\bar{X}_k - \bar{X}_p)^3 - (\bar{X}_k - \bar{X}_{p+1})^3 \right] Y_k,$$

$$1 \leq p \leq n - 1 \qquad (42)$$

Discussion and further simplification.

The $n + 2$ equations, Eqs. (31) to (34), are adequate when $\lambda_2 \neq 0$.
However, when $\lambda = 0$ the determinant of the set vanishes as λ^2 times
a polynomial in λ of degree $(n - 2)$. The vanishing of the
determinant for $\lambda = 0$ is not surprizing, if one considers that
this case corresponds to dropping the condition of minimum
curviness, and thus reducing the problem to a simple least
squares fitting of W points with an $n + 2$ parameter form.
Since n parameters are adequate to make the curve pass exactly
thru all the points (thus reducing σ^2 to its absolute minimum
value, zero), two parameters can be chosen arbitrarily. Thus,

two equations are redundant and must be consequences of the others. This is manifested by the occurrence of λ^2 as a factor of the determinant.

On the other hand, we have two additional conditions, Eq. (12), which by Eq. (36) are

$$y'' (\bar{X}_1) = y'' (o) = 2 C_1 = o \tag{43}$$

and

$$y'' (\bar{X}_n) = 2 (C_{n-1} + 3D_{n-1} \bar{X}_n) = o \tag{44}$$

which must hold for any choice of λ, and thus in the limit of $\lambda \to o$. This permits us to drop two of the equations of the set (31) - (34), and replace them by Eqs. (43) and (44).

Eq. (43) gives $C_1 = o$, and may be used to simply drop all terms in Eqs. (31) - (34) containing C_1 as a **factor**. Eq. (44), in wiew of Eq. (25), reduces to

$$\sum_{m=1}^{n-1} (\bar{X}_{m+1} - \bar{X}_m) D_m = o. \tag{45}$$

Summary

We take as the final basic set of equations the following $n+1$ equations:

$$L = 0; \tag{46}$$

$$M = 0; \tag{47}$$

$$N + \lambda R = 0; \tag{48}$$

$$Q_p + \lambda P_p = 0, \quad 1 \le p \le n - 3; \tag{49}$$

$$\sum_{m=1}^{n-1} (\bar{X}_{m+1} - \bar{X}_m) D_m = 0, \tag{50}$$

for the $n+1$ unknowns: $A_1, B_1, D_1, \ldots D_{n-1}$, where L, M, N, P_p, Q_p, R are given by Eqs. (37) - (42), with $C_1 = 0$.

When these are solved for any assumed λ_1 we use

$$C_1 = 0; \tag{51}$$

$$C_k = 3 \sum_{m=2}^{k} (D_{m-1} - D_m) \bar{X}_m; \quad 2 \le k \le (n-1) \tag{52}$$

$$B_k = B_1 - 3 \sum_{m=2}^{k} (D_{m-1} - D_m) \bar{X}_m^2; \quad 2 \le k \le (n-1) \tag{53}$$

$$A_k = A_1 + \sum_{m=2}^{k} (D_{m-1} - D_m) \bar{X}_m^3 \quad '' \tag{54}$$

With all $4(n-1)$ coefficients known, we can calculate $y(\bar{X})$, for $\bar{X}_k \le \bar{X} \le \bar{X}_{k+1}$, by the formula

$$y(\bar{X}) = A_k + B_k \bar{X} + C_k \bar{X}^2 + D_k \bar{X}^3. \tag{55}$$

Determination of λ

From the knowledge of experimental technique it is possible to estimate the standard deviation of the meaured values of Y, that is σ. In general the exact value of σ is unknown, and in fact unnecessary. Let us assume that it is decided that σ should lie between σ_1, and σ_2. It is then required to find a value of λ for which σ would lie in this range.

λ as a function of σ has the following properties: For $\sigma = 0, \lambda = 0,$ except when all points lie exactly on a straight line - a trivial case requiring no curve fitting. Increasing λ will in general increase σ, again except for the straight line case, when $y'' \equiv 0$ and λ has no effect on σ. If $\lambda \to \infty$, the curve approaches a straight line and σ^2 will have its maximum value, say σ_m^2, corresponding to the best fitting straight line. Thus, in general, λ is a monotonically increasing function of σ, starting at $\lambda = 0$ for $\sigma = 0$, and becoming asymptotically infinite for $\sigma = \sigma_m$.

For small σ, λ will in general be proportional to σ. This can be seen by assuming that λ is expanded in powers of σ and noting that, since $\lambda = 0$ for $\sigma = 0$, the constant term is missing.

Based on this behavior of λ, we suggest the following procedure for determinimg a suitable λ.* Assume an arbitrary $\lambda = \lambda_1$ and having gone thru the calculations described in the last previous section of this report, determine corresponding σ. Test to see if this σ lies between σ_1 and σ_2. If not, let λ_2 be found from the equation

$$\lambda_2 = \frac{\lambda_1}{2} \frac{(\sigma_1 + \sigma_2)}{\sigma}, \tag{56}$$

and repeat.

---

* This method was suggested by Dr. J. H. Bramble.

Practical difficulties.

While theoretically the set of equations (46)-(50) appears satisfactory, in practice they are very ill-conditioned. They have been programed for use on IBM - 704 and gave good results when n did not exceed 6. For n = 8 or more results were very poor especially for small λ .

We have, therefore, attempted to find another set of equations, equivalent to the set (46)-(50), but better conditioned. The attempt was gratifyingly successful and is described below.

Well-conditioned equivalent set.

When λ = 0, the curves given by Eq. (50) pass through all the given points. In that case, however, the coefficients A_k, B_k, C_k, and D_k can be found more directly. We can still use Eqs. (52)-(54), the continuity conditions. There are 3(n-2) of these equations. Further, the end point conditions, Eqs. (45) and (51), provide two additional equations. Finally Eq. (55) has to hold at n points, giving n additional equations. Thus, in all we have 3(n-2) + 2 + n = 4(n-1) equations, which is just equal to the number of unknown coefficients in Eq. (55).

When A_k, B_k, and C_k are replaced by their values from Eqs. (51)-(54), Eq. (55) becomes, for $X = X_k$, k = 1, 2,....n

$$A_1 + B_1 X_k + \sum_{m=1}^{k-1} \left[(X_k - X_m)^3 - (X_k - X_{m+1})^3 \right] D_m = Y_k \qquad (57)$$

This set of n equations is equivalent, for λ = 0, to the set (46)-(49). This can be seen as follows:

If the n equations (57) are added together, in other words, if the two sides of (57) are summed over k, from k = 1 to k = n, the result is Eq. (46). If eq. (57) is first multiplied by X_k and then summed over k, the result is Eq. (47), etc. In general, each of the equations (46)-(49) is obtained from Eq. (57) by first multiplying it by a suitable function of X_k and then summing over k. The suitable factor can be easily seen by noting the factors by which Y_k is multiplied in Eqs. (39)-(42).

Now, the idea behind our attempt to improve our equations is to replace them by a generalization of Eq. (57), involving terms in λ, which would be equivalent to the set (46)-(49) even when $\lambda \neq 0$. We first tried the equation;

GT 2063-C1 (10-52)

$$A_1 + B_1 X_k + \sum_{m=1}^{k-1} \left\{ \left[(X_k - X_m)^3 - (X_k - X_{m+1})^3 \right] + \lambda f_{k\,m} \right\} D_m = Y_k$$

but it soon became obvious that this set cannot be made equivalent to the set (46)-(49) for any choice of f_{km}. The generalization that worked was:

$$A_1 + B_1 X_k + \sum_{m=1}^{k-1} \left[(X_k - X_m)^3 - (X_k - X_{m+1})^3 \right] D_m$$

$$+ \lambda \sum_{m=1}^{n-1} f_{km} D_m = Y_k \qquad (58)$$

This set of n equations ($k = 1, 2_1 \ldots n$) replaces Eqs. (46)-(49) and must be used with Eq. (50) to determine $A_1, B_1, D_1, D_2, \cdots D_{n-1}$. After these are obtained, Eqs. (51)-(54) give the remaining coefficients.

The problem was thus reduced to finding coefficients f_{km} ($k = 1, 2, \cdots n$; $m = 1, 2, \cdots n-1$). Operating on Eq. (58) in the same way that we operated on (57), and comparing the results with Eqs. (46)-(49), we obtain conditions on f_{km}. Thus, for example, summing Eq. (58) over k, from 1 to n, we obtain Eq. (46), provided

$$\sum_{k=1}^{n} \sum_{m=1}^{n-1} f_{km} D_m = 0$$

If we assume, as we did, that f_{km} are independent of D_m, then

$$\sum_{k=1}^{n} f_{km} = 0. \qquad 1 \leqslant m \leqslant n-1 \qquad (59)$$

Similarly, we obtain the following conditions:

$$\sum_{k=1}^{n} X_k f_{km} = 0, \qquad 1 \leqslant m \leqslant n-1 \qquad (60)$$

$$\sum_{k=1}^{n} X_k^2 f_{km} = 3(X_{m+1} - X_m)(2X_n - X_m - X_{m+1}), \qquad (61)$$

GT 2063-C1 (10-52)

with the same condition on m. Further equations are:

$$\sum_{k=p+1}^{n} \left[(X_k - X_p)^3 - (X_k - X_{p+1})^3 \right] f_{km}$$

$$= 9(X_{p+1} - X_p)(X_{m+1} - X_m)(2X_n - X_p - X_{p+1})$$

for $\quad 1 \leqq p \leqq n - 3 \quad$ and $\quad 1 \leqq m \leqq p - 1$

On the other hand, the right-hand member becomes

$$= 9(X_{p+1} - X_p)(X_{m+1} - X_m)(2X_n - X_m - X_{m+1})$$

for $\quad 1 \leqq p \leqq n - 3 \quad$ and $\quad p + 1 \leqq m \leqq n - 1.$

Finally

$$\sum_{k=p+1}^{n} \left[(X_k - X_p)^3 - (X_k - X_{p+1})^3 \right] f_{kp}$$

$$= 6 (X_{p+1} - X_p)^2 (3X_n - X_p - 2X_{p+1})$$

for $\quad 1 \leqq p \leqq n - 3$

The set of equations (59)-(64) has $n(n-1)$ independent equations, which is just the number of f_{km}.

Looking at Eq. (58) we see that any common factor of all f_{km} can be taken out and included in λ, since λ is arbitrary. The right-hand members of Eqs. (59)-(64) all have a factor 3, which can therefore be omitted. The f_{km} satisfying these equations can be divided into 3 groups.

Group I, when $\quad 1 \leqq k \leqq n-3$, and $1 \leqq m \leqq n-1$:

$$f_{km} = 0 \qquad \text{for } k < m$$

$$= 1 \qquad \text{for } k = m$$

$$= -1 \qquad \text{for } k = m+1$$

$$= 0 \qquad \text{for } k > m+1$$

GT 2063-C1 (10-52)

<u>Group II</u>, for $k \geq n - 2$ and $1 \leq m \leq n - 4$

$$f_{n-2, m} = \frac{(X_{m+1} - X_m)(X_n - X_{n-1})}{(X_{n-1} - X_{n-2})(X_n - X_{n-2})}$$

$$f_{n-1, m} = \frac{-(X_{m+1} - X_m)(X_n - X_{n-2})}{(X_n - X_{n-1})(X_{n-1} - X_{n-2})}$$

$$f_{n, m} = \frac{(X_{m+1} - X_m)(2X_n - X_{n-1} - X_{n-2})}{(X_n - X_{n-1})(X_n - X_{n-2})}$$

<u>Group III</u>, for $k \geq n - 2$ and $m \geq n - 3$ has the following nine members:

$$f_{n-2, n-3} = \frac{(X_n - X_{n-1})(X_n - X_{n-3}) - (X_n - X_{n-2})^2}{(X_n - X_{n-2})(X_{n-1} - X_{n-2})}$$

$$f_{n-1, n-3} = \frac{-(X_n - X_{n-1})(X_{n-2} - X_{n-3})}{(X_n - X_{n-1})(X_{n-1} - X_{n-2})}$$

$$f_{n, n-3} = \frac{(X_{n-2} - X_{n-3})(2X_n - X_{n-1} - X_{n-2})}{(X_n - X_{n-1})(X_n - X_{n-2})}$$

$$f_{n-2, n-2} = \frac{(2X_n - X_{n-1} - X_{n-2})}{(X_n - X_{n-2})}$$

$$f_{n-1, n-2} = -\frac{(2X_n - X_{n-1} - X_{n-2})}{(X_n - X_{n-1})}$$

$$f_{n, n-2} = \frac{(X_{n-1} - X_{n-2})(2X_n - X_{n-1} - X_{n-2})}{(X_n - X_{n-1})(X_n - X_{n-2})}$$

$$f_{n-2, n-1} = \frac{(X_n - X_{n-1})^2}{(X_n - X_{n-2})(X_{n-1} - X_{n-2})}$$

GT 2063-C1 (10-52)

$$f_{n-1,\, n-1} = \frac{-(X_n - X_{n-1})}{(X_{n-1} - X_{n-2})}$$

$$f_{n,\, n-1} = \frac{(X_n - X_{n-1})}{(X_n - X_{n-2})}$$

For $n = 4$, Group II is vacant; for $n = 3$ both Group I and Group II are vacant. For $n = 4$, Group I reduces to three members, namely:

$$f_{11} = 1, \quad f_{12} = f_{13} = 0.$$

Acknowledgements

GT 2063-C1 (10-52)

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TECHNICAL INFORMATION SERIES
Title Page

AUTHOR	SUBJECT CLASSIFICATION	NO.
Boris Podolsky	Mathematics	R59FPD442
		DATE
		7-21-59

TITLE Curve Fitting With Allowance For Errors In Given Data

ABSTRACT   A method is presented for finding the smoothest curve the standard deviation of which from a set of given points lies within prescribed limits. If desired the curve may be made to pass through the given points at some sacrifice in smoothness.

G.E. CLASS	REPRODUCIBLE COPY FILED AT	NO. PAGES
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GOV. CLASS. Unclassified		

CONCLUSIONS While the method presented in this report may be considered generally satisfactory; it is expected that in cases when $d^2y\,dx^2$ is large at one or both end points some difficulties may occur.

INFORMATION PREPARED FOR_____

TESTS MADE BY_____

COUNTERSIGNED _Charles H Warlick_____ OPERATION___Testing_____

DIVISION ___FPD_____ LOCATION___Evendale, Ohio_____

MA-GO

GT 2063-A1 (10-57)

MSVD Progress
in
Generalized Programming
on the
704 Computer

PRESENTED BY:

P. Ravitch

at the

ENGINEERING
COMPUTER
USER SYMPOSIUM
MAY 19, 20, 1959

WARWICK HOTEL · PHILADELPHIA, PENNA.

INTRODUCTION

This booklet has been prepared by Computer Data Processing, Quality Control and Test, MSVD, Philadelphia. By no means is it meant to reflect the entire scope of the workload handled by this group but rather the progress that has been made in generalizing data processing on the 704 Computer. We realize that we are relatively new in this field, but in the space of a few months, ambitious programs have been undertaken, accomplished, and placed into productive operation. The resultant yields were indeed rewarding -- some fine savings, program integration, and a greater acceptance of the merits of generalized programming.

Progress has come rapidly, and so have the modifications. Each step forward has meant a retracing of effort to consolidate and eliminate redundancies in whatever work was done before. This has not been an easy job, and there is still more to be done. Each day, it appears that we are only inching our way forward but the net cumulative effect has been far greater. The inches have become a giant step and our painstaking work has resulted in significant accomplishments. This is the story which we wish to relate.

Section One of this paper contains a general description of our system, our history, and what we are presently planning as additions or improvements to our program. A sample data processing problem involving all the routines is described in Section Two. Cost Estimate Data was selected for its common usage at most installations and because it is unclassified information that we are permitted to describe. The Cost Estimate Program provides cost estimates incurred by personnel and computing equipment in behalf of the particular jobs within the department's operation.

SECTION I

GENERAL DESCRIPTION OF THE SYSTEM

Though initially the programming effort at MSVD was mainly used for flight test data processing and solution of engineering problems, an increasing volume of business-type data processing requests have been channeled through Data Processing & Computation Operation. These problems are business-type in that many of our customers need sorts, merges, reports, file maintenance, and some interrogation to accomplish their data processing requirements. What most of you have probably noticed at your own installations is that customer computer requests are basically the same in nature but different in detail. Bearing this in mind, and concentrating on the more routine facets of data processing, we devoted our attentions toward generalized programming. See Figure 1.

Since no group exists at MSVD whose sole interest is advanced techniques, our approach to generalized programming has been to prepare the generalized programs only when a specific application arose, and to partially defray this cost with funds budgeted for that specific application. Therefore, our generalized system has grown by using each new requirement as justification for subsequent expansion. Quite often, these generators had a limited range because the customer's needs did not encompass the full extent of generalization. But as time passed, we have tried to develop a highly flexible system. Modification of programs, widening of ranges, consolidation of separate runs into one-pass routines and relaxation of restrictions have become a regular occurrence.

Obviously, the first few generalized applications were more expensive than the specific programs would have been and, in addition, they took a longer time to prepare. However, in the period since 1 January 1959, several cost improvements have been credited to our program; each subsequent application will result in still more savings. Thus, the extra money spent to produce these routines has more than paid for itself. Savings by the 704 computer are estimated at the overtime rate of $65.00 per hour and a bit more than $4.00 per hour per programmer.

Like any other system, there are basic ground rules which are needed for integrating the program to enable customers to utilize commonly defined packets rather than tailored individual programs. For a start, we preferred to work with fixed-length records of no more than one hundred words and only one physical file per reel, although the logical file may extend over several reels. In all cases, other than the report routine, where only BCD mode is accepted, data may be in either the BCD or binary mode, and in any case, may also be numeric, alphabetic, or alphanumeric in content. In addition, up to 15 different masks may be utilized for extracting key words in the sort, merge, file maintenance, and word convertor routines. Each run (except for the report routine, which by nature is usually a final processing routine) has the option of reading in the next run for subsequent processing or halting after completion. Most of the ground rules we adopted were restrictions in the generalized sort which we did not program ourselves, but we accepted them in our sort program to get the project under way. Unless otherwise specified in this writeup, all our runs have the aforementioned restrictions. See Figure 2.

The following are some highlights of our generalized routines. They are currently being used or they are being readied for customer use.

CURRENTLY GENERALIZED ROUTINES

1. SORT (WORD CONVERTOR)

2. MERGE

3. REPORT

4. FILE MAINTENANCE

5. SELECT

6. ARITHMETIC

FIGURE 1

GROUND RULES FOR OUR
GENERALIZED SYSTEM

1. BCD OR BINARY DATA, EXCEPT FOR ONE ROUTINE

2. FIXED RECORD LENGTH, EXCEPT FOR ONE ROUTINE

3. MAXIMUM RECORD SIZE OF ONE HUNDRED WORDS

4. MOST RUNS HAVE OPTION OF READING IN NEXT PROGRAM

5. UP TO 15 MASKS IN RUNS THAT REQUIRE GENERALIZED EXTRACTION

6. NO LABELS OR DIRECTORIES PROVIDED

FIGURE 2

For sorting purposes we use the Harriet R. Meadows Sort Generator (GI Sort No. 404). This routine generates a running program deck based on parameter card information. Each generated routine sorts items requiring as many as 15 keys. A key word may be an entire word or any portion of a word and may be anywhere within a record. Only one reel at a time may be sorted; two or more reels require a merge after sort. The sort is relatively slow and inefficient but it accomplishes all that is asked of it. We estimate that it would take three months to develop a more efficient sort but, so far, no customer has been willing to assume the financial burden for its development.

To further aid customers in sorting, we have developed a generalized word convertor routine. This routine converts BCD alphanumeric data to binary pseudocodes, and in turn, sorts and subsequently decodes them into their original BCD alphanumeric state. This procedure enables us to sort on such keys as government stock numbers according to the various peculiar sequences demanded. In some cases, alphabetics must precede numerics; in others, blanks must precede zeros and for another type of breakdown, dashes within stock number must precede any other designation. Of course there are sequence problems other than these that customers will request, and by completion of parameter cards according to specifications any desired sequence can be attained.

At the present time we are investigating ways to use the word converter in the first and last pass in the sort. This would save us one pass of input during each processing cycle. Since read/write time for the processing of magnetic tape input on the 704 computer is rather slow, the elimination of two tape passes per processing cycle can result in a considerable saving.

Wherever there is sorting, especially for multi-reel sequencing, merges are generally required for further processing. Initially, we decided to make our merge as simple as possible.

This program can merge two to five separate files of data. The program checks each tape separately for sequence. When there is a break in sequence, the run halts and no further merging takes place beyond this point. Two reels are provided for output with automatic switching of these units for multi-reel files. Options are also provided to include hand coded subroutines and for loading program decks that are fed-in by parameter cards.

With a bit more experience under our belts, we are starting to think of more sophisticated component subroutines for the merge. The following improvements have been added to the merge, which make it a much more useful and powerful tool for our data processing needs.

1. An option to process numeric information only. This speeds up the processing of such data because alphabetic information requires more tests than numeric data.

2. A redundancy tape test (RTT) option. This will print on line the record in error and indicate which tape it came from. The record will be eliminated from the merge and the program will either continue or stop as determined by a signal feed-in on a parameter card at generation time.

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With a bit more experience under our belts, we are starting to think of more sophisticated component subroutines for the merge. The following improvements have been added to the merge, which make it a much more useful and powerful tool for our data processing needs.

1. An option to process numeric information only. This speeds up the processing of such data because alphabetic information requires more tests than numeric data.

2. A redundancy tape test (RTT) option. This will print on line the record in error and indicate which tape it came from. The record will be eliminated from the merge and the program will either continue or stop as determined by a signal feed-in on a parameter card at generation time.

3. Two "out-of-sequence" options. One option will print on an error tape all records that are out of sequence, eliminate these records from the merge and continue. The out-of-sequence tape may then be re-sorted and merged with the master file. Our second treatment would be the one that is currently in use --- to stop the run when an out-of-sequence item is encountered. If no RTT error has occurred or no records are out of sequence, the condition will be so indicated by a print out on-line.

4. An equal conditions option to go into a series of hand coded subroutines that will process the "equal" records. This is used temporarily to take care of file maintenance until the later program is checked out.

5. Lastly, a variable length records option. This is a refinement that has added a bit of versatility to the merge. It permits variable length records coming from the same tape or any of the five tapes to be merged. Many customers need this bit of freedom, especially those who are maintaining records of transactions by account. It is impossible to know the exact number of transactions for any one account, therefore variable length records are needed for greater efficiency in file maintenance and for insertion, as well as deletion of all entries as they occur. The only restriction that we place on the use of variable length records is that the keys must be in the same position in each record. With careful record design, a customer should be able to pass variable length records which will meet this stipulation.

A highlight of our budding generalized program system is the Report Generator. It is patterned after our Output Generator for Scientific Data. To use the program, the customer completes forms which describe the format of the report and give the source of the information. The completed forms can be turned over to a keypunch operator and cards can be punched directly from the form information.

After the parameters have been punched, the generator produces the program that will output the report according to parameter specifications. The following features are a functioning integral part of the report routine.

Input, which must be in the BCD mode, may come from a sort, a selection routine, or from another run not necessarily linked with the report routine. Output can be printed on either small (8 1/2 in. x 11 in.) or large (11 in. x 16 7/8 in.) forms, single or double spaced, and with or without leading zeros.

Page numbers can be provided in several ways. No matter what the customer preference may be, upper right hand corner, lower right hand corner, or no page number at all, this routine will satisfy all numbering requirements.

The printed form can be arranged in any layout as long as it satisfies the following specifications. Each page may have a heading, data lines, summary lines, and final lines. The page heading is limited to nine printed lines for any page. Up to nine data lines per record are permitted, with the selection of the number of data lines per page being a personal choice, subject to the physical size of the paper.

For specifiable control breaks, summary lines can be printed for intermediate totals. These lines can occur anywhere on the page and there can be any number of them; but a nine-line output is the maximum for any one control

break. Final total breaks on each report are provided for, if desired, and up to nine lines of printed output can be reserved for them. The number of totals per report should not be greater than twenty and each total should not exceed twelve decimal digits. Nine lines of footnotes are available for each page of output.

Currently the report can only handle one report at a time, but we plan to accommodate up to four reports simultaneously as a future revision to this routine. A typical report is shown in Figure 3.

File Maintenance is currently being programmed. The following are a few observations on what we are presently attempting to do in this area:

1. If the file maintenance run is fully utilized, all ten tape units will be required as follows:

    a. Three (3) tape units will be required for input. Two of these units will be used for the master file. They will be multi-reel for changing back and forth between adjacent tape units until the master file is exhausted. The third unit will be used for updating information or changes. All input files will be sequence checked. A redundancy test feature will also be provided.

    b. Four (4) tape units will be provided for non-optional outputs. Two of these units are used for the updated master file (including a multi-reel change feature); one unit used for out-of-sequence change items which will be sorted and reprocessed, and one unit will record errors. The error tape will contain miskeyed and miscoded changes which must be correctly inserted at a later time.

    c. Three (3) tape units will accommodate optional outputs. One optional unit tape is a report tape on which any specific report information can be written. The second optional unit tape accommodates inactive items. Once an item is placed on inactive status and this option has been selected, an inactive record will be made on the separate inactive file. The third unit tape accommodates an audit trail output. It will show the old field prior to change, the newly inserted field and the key word identification of the item that has been changed. If the inactive and/or audit trail file is not selected as an optional output for these units the tape normally used for this information will accommodate the multi-reel output for the report routine.

2. At the present time this routine anticipates performing the following file maintenance functions:

    a. Deleting a master record

    b. Replacing a master record that already exists on the file

    c. Adding a new record to the master file and changing any number of fields housed within a master record.

Change items may contain any number of changes subject to the columnar limitation of the card, but in no case can change data for the last field correction he carried-over and punched on the next card.

FISCAL   WEEK   51

7 0 4   C O M P U T E R   U S A G E
F O R   S E L E C T E D   P R O G R A M   R E C O R D S

PR NO.	DPC NO.	CHECK OUT TIME	PRODUCTION TIME	ERROR TIME	TOTAL TIME
Q175	6Q.1.01	01.35	00.00	00.00	01.35
Q574	6B.2	00.66	00.00	00.00	00.66
Z443	2Z.4.01	00.38	01.22	00.00	01.60
Z551	2Z.3	00.00	00.11	00.00	00.11
	TOTAL	2.39	1.33	.00	3.72

NOTE   ALL TIMES ARE EXPRESSED IN HOURS.

FIGURE 3

In this case the field must be started on the next card. The master record directory and self-generated routines will be used extensively for the execution of the change functions that are desired. Also, for individual customer usage, core will be supplied for up to five hand-coded subroutines. These routines will be available at the completion of updating on each master record.

A form of generalized file interrogation has been developed and is currently being used -- it is our selection routine. This routine selects a specific value, within a range, or, within a combination of ranges, on any given fields within a record. The selection may be made to satisfy two or more conditions (the "and-and" type selection) or to satisfy one of many conditions (the "either-or" type selection). The program also provides an option for further processing of data after a selection has been made.

Unlike some of our other routines, output must conform to input in mode and record length, and shall contain all of the selected records of data. A fine example of the usefulness of this routine can be seen in Section II of this paper.

In most discussions on generalized programming, little is said about arithmetic operations than the almost terse remark "users will supply their own hand-coded routines to execute arithmetic functions". We have gone a step beyond this and are trying somewhat to generalize BCD arithmetic. A routine is being tested which will do any combination of addition, subtraction, multiplication, division, and calculation of square roots. The routine will pick up the numbers from any specified core location, convert them to floating-point binary and, in turn, will store the BCD result in any field. Admittedly, this is not a major break-through in generalizing arithmetic for commercial applications, but it is certainly a welcomed improvement over what is otherwise available.

A complete system for the processing of Air Force Contract 673 (Spare Parts Provisioning) has been set up and is a good example of how generalized programming can be used to good advantage.

The main chain consists of several runs. In the first run, our change file will be sequence checked. If out of sequence, the out-of-sequence items will be sorted and merged with the change file. All of these components of the first run are generalized programs that have been discussed today. The second run is an indexing run that will key changes so that they are applied everywhere within the master file wherever the same part number is contained. This routine must be hand-coded; but we can make full use of the generalized merge logic and coding. The third run is a sort which will be generated by the Harriet Meadows' routine. The fourth run, the file maintenance run, is currently being generalized. The fifth run, the reports processor run prepares the required provisioning documents and is the Generalized Reports Routine.

Out of the five runs that are components of the system, only one must be hand-coded, and that is generalized up to its main flow of logic. We hope that further prudent usage of generalized programming becomes a common situation. In the long run, generalized programming should more than pay for itself.

We are already saving programming time and money through wider usage of what little we have generalized. Several cost improvements have been credited to our program and there are quite a few more pending. Streamlining of effort is also taking place in our system. The select routine and reports routine have been combined to function as one integral program to process a given file for both options in only one pass of data. Whenever we can accomplish it, other functions will be merged to save data passes. Our program will be continually improved and through improvement we will save even more programming time and money.

SECTION II

SAMPLE PROBLEM

The master file, file 1, is on tape.

The file which is to be merged with the master file is on cards. The card format is as follows:

Field No.	Card Column	Description of Data
1	1	Card Code
2	2-5	PR Number - major key
	6	Blank
3	7-13	DPC Number - intermediate key
	14	Blank
4	15-16	Fiscal Week
5	17-19	Time Control
6	20	Special Control (if any)
7	21-24	Total Time (hundredths of hours)
	25-60	Blank
8	61-64	Error Time (hundredths of hours)
	65	Blank
9	66-69	Checkout Time (hundredths of hours)
	70	Blank
10	71-74	Production Time (hundreths of hours)
	75-78	Blanks

NOTE: Minor key field (name) is blank in this file.

The information in these cards is transferred to tape in the form of 13 word records. The format of each record (or item) is shown on the next page.

Word Convertor Run

Subsequent to this run, we wished to merge file 2 with file 1 in order by PR* number, DPC** Number and name. The name field is not used in file 1. File 2 represented changes for computer component time and we wanted them to precede all other changes within the PR and DPC when listed. The 704 computer has its own codes for recognizing alphanumerics and, in normal processing, a blank would fall between R and S in magnitude. It was obvious that some sort of pseudocode was needed to modify this file so that blanks would precede all alphanumerics in the merge that followed.

By filling in the following forms, and having parameter cards punched from them, this was accomplished. File 2 was then converted into a binary pseudocode, merged with the binary mode master file 1. The first form describes what basic parameters are wanted: which pass, size of record, whether next run is to be in directly, the up-to-fifteen masks that are required, and which word in

*PR - programming record
**DPC - data processing charge

WORD	1	2	3	4	5	6	7	8	9	10	11	12	13

| FIELD | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | | 8 | 9 | 10 | |

```
XXXXX0XXXXXXXX0XXXXXXXXXXX0000000000000000000000000000000000XXXX0XXXX0XXXX0000
```

ITEM LAYOUT ON TAPE

WORD CONVERTOR INPUT LAYOUTS (OPTIONS)

	Columns 1 - 6	Columns 7 on ⟶		
	OPTION	1 = encode 2 = decode 1,	words/ record 13,	read next deck 0 = yes O 1 = no
Card 1	Mask ooooxo	Word No. 7		
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
	ZZZZZZ			

Omit any mask cards which are not used.
All fields from col. 7 on should be separated by commas.

the record they are to be used for extracting. For this application, we were processing option one on a thirteen word record and we wanted to read the merge immediately as a continuous process. The name started in column forty-one. Only one blank had to be converted to precede any other alphanumeric name because the name field on the master record was completely alphabetic and, therefore, a zero must precede any alphabetic character. The correct mask and word number are shown. All necessary conversions are shown in the table to be punched from form two. Note carefully that the blank is coded zero and that the other alphanumerics are higher in magnitude than the blank. Decimal equivalents of the selected codes are in the table.

Sort Run

To generate the sort to sequence the second file into PR number and DPC number order, the statements which follow must be punched, one parameter per card, and in the sequence shown. Input tape number is one. Tape units two, three, four and five are going to be used in the sort collation passes. Since we want our output on either four or five, the output tape numbers are arranged in card number two as 4253. Input tape mode is binary because the file being sorted has been coded and written in binary mode by the word convertor. Thirteen is our item length and in addition, is the record length. Since we are sorting one file, the number of files is 1. Indication is made in the next two cards respectively that we want neither an input checksum, nor an output checksum. Having no sentinel provision on this file, sentinel in octal is shown as twelve zeros. The program is on a card deck and the run to be read in following this run is also on cards. Sense light two will be used by the run to signal whether the output is on tape unit four or five, depending upon light status. These keys are used in the sort: one key for the PR number (major key), and two for the DPC number because it takes up two words in core (minor key). All keys are alphabetic (this is indicated in column 30 with an "A"). Beneath each punch-notation for keyword location and type of data is the appropriate mask for extraction. NSB in column 30 of each mask card is an abbreviation for no substitution for blanks. A card that reads END follows the last parameter card.

After the cards are read in, the pertinent sort is generated. The deck punched out on line is then used to sort our second file. This file will then, in turn, be merged with the master file for subsequent decoding into BCD by Option Two of the word convertor.

WORD CONVERTOR INPUT (CODING)

Card no.	Columns 1 - 6	Column 7 on → All fields from col. 7 on are separated by commas.							
1	TABLES	0 / 2,	1 / 3,	2 / 4,	3 / 5,	4 / 6,	5 / 7,	6 / 8,	7 / 9
2	TABLES	8 / 10,	9 / 11,	0 / 0,	# / 40,	@ / 41,	0 / 0,	0 / 0,	0 / 0,
3	TABLES	& / 38,	A / 12,	B / 13,	C / 14,	D / 15,	E / 16,	F / 17,	G / 18
4	TABLES	H / 19,	I / 20,	+ 0 / 42,	. / 43,	⧠ / 44,	0 / 0,	0 / 0,	0 / 0,
5	TABLES	- / 45,	J / 21,	K / 22,	L / 23,	M / 24,	N / 25,	0 / 26,	P / 27,
6	TABLES	Q / 28,	R / 29,	- 0 / 46,	$ / 47,	* / 39,	0 / 0,	0 / 0,	0 / 0,
7	TABLES	blank / 0,	/ / 48,	S / 30,	T / 31,	U / 32,	V / 33,	W / 34,	X / 35,
8	TABLES	Y / 36,	Z / 37,	‡ / 49,	, / 50,	% / 51,	0 / 0,	0 / 0,	0 / 0,

13

SORT PARAMETERS

INPUT TAPE NUMBER 1

BLANK TAPE NUMBERS 4 2 5 3

INPUT TAPE MODE BINARY

ITEM LENGTH 13

RECORD LENGTH 13

NUMBER OF FILES 1

INPUT CHECKSUM NCS

OUTPUT CHECKSUM NCS

SENTINEL IN OCTAL 000000000000

THIS PROGRAM ON CARDS

NEXT PROGRAM FROM CARDS

WHAT LIGHT MAY PROGRAM USE 2

NUMBER OF KEYS 3

KEY WORD 1 1   A

MASK 1 007777777700   NSB

KEY WORD 2 2   A

MASK 2 007777777777   NSB

KEY WORD 3 3   A

MASK 3 770000000000   NSB

END

Merge Run

Two files are to be merged on 3 key fields. These fields are PR number in columns 2-5, DPC number in columns 7-13, and Name in columns 41-50. To set this problem up for the merge routine, a merge parameter specification form is filled out as described below.

Card 1 on this form is a Tape Failure Option card. Since we do not want the run to stop on a redundancy tape test failure, a zero is placed in column 7. Since the input has just come from the sort, no records should be out of sequence,

14

therefore no error tape would be required. Any records out of sequence would indicate a machine error. By placing a "zero" and a "1" separated by a comma on card 2, a stop will occur if there is an out-of-sequence condition. Since the DPC number starts with an alpha character in column 7, a "zero" is placed in column 7 of card 3. Card 4 will also have a zero in column 7, since no subroutines are needed. We place a -1 in the first field of card 5 (SETCRD) since the tape is in Binary Mode (1) and the decoder routine is to follow (-). The records are all 13 words in length so this number is placed in field 2. Since the merge is to follow a sort, a "1" is placed in field 3. A "2" will be placed in field 4 and a "1" in fields 5 and 6, since we are merging two tapes having one reel each. The remaining fields are left blank.

By examining the 3 key fields, it is determined that 6 masks are required. The PR field in columns 2-5 is the first mask. It is placed as shown in Key word 1. Since this is the first word of the input record, a "1" is put in column 7. The DPC number will require two masks: one for columns 7-12 in word 2 of input and a second for column 13 in word 3 of input. These will be placed in Key words 2 and 3 respectively, as shown on the form.

The name field requires 3 masks: one for columns 41-42 in word 7 of input, a second for columns 43-48 in word 8 of input, and a third for columns 49-50 in word 9 of input. These will be placed in key words 4, 5, and 6 as shown on the form. The last card on the form contains a series of Z's. These are used to terminate the mask cards.

A set of cards will be punched from this form. When these are placed in the proper position in the merge deck the deck is ready for use. The master file is mounted on tape unit 6. The file coming from the sort will be on either unit 4 or 5. The output will be on unit 2. Any tape failures will print the record on line and the merge will continue. Any records out of sequence will cause a stop. After completion of the run, the program will transfer control to the card reader which will read in the decoder program deck.

Deconverter Run

Immediately after the merge, we wished to decode the pseudocodes to their original BCD form. This would preserve the original characters for listing and would not affect the sequence of items which was correct (blanks preceding other alphanumerics). Two forms have to be filled in, so that the necessary parameter cards can be punched. The first form is exactly the same one used in pseudocoding this file. Basic parameters that we again want are: which option, size of record, whether the next run is to be read immediately as a continuous process, masks required and which words in the record were to be used for extracting. In this case, option two was required to decode a thirteen word record and the next run, the select routine was to be read immediately as a continuous process. Only one mask was needed as we only pseudocoded one word previously in option one. Here again, the mask is to extract from word seven of the record.

The second form to be filled out is slightly different than form two of option one. What we have to fill in here is the decimal equivalent of the original character that the given pseudo character replaced. For example, blanks were pseudocoded zero, therefore in the box capped with a numeric zero, we enter the decimal equivalent of a blank (60 octally) or 48. All other substitutions shown were made using the same principle. For every pseudocode used in option one, a decimal entry must be made in the appropriate box.

MERGE
Parameter Specifications

NAME _____

Card 1 col. 1 ——→6 7 TP.FAIL [0]

Tape Failure Option

0=continue
1=stop run

Card 2 col. 1 ——→6 7 SEQCHK [0][1]

Sequence Check Option

Tape no. of output. 0=no tape written. 0=continue run 1=stop

Card 3 col. 1 ——→6 7 ALPHNUM [0]

Alpha Numeric Option

0=alpha
1=numeric

Card 4 col. 1 ——→6 7 SUBRUT [0][ ][ ][ ]

subroutine option

0 = no subroutine dec. address of subroutine (5 max)

Card 5

col. 1 ——→6 7
Field

SETCRD	1	2	3	4	5	6	7	8	9
-1,	13,	1,	2,	1,	1,				

Identification

0=BCD mode
1=binary mode
-0 or -1=next program from card.
no. of words per record
0=variable length records
1=merge follows sort.
0=all others
Number of tape units to be merged.
number of reels of input on tape units 5, 6, 7, 8 and 9 respectively. (use as many units as required by parameter 4)

Use one key card per word in field. Arange cards from major to minor keys.

Key word 1 col. 1 ——→6 7

1 [0 xxxxo] [1]
2 [x xxxxx] [2]
3 [xooooo] [3]
4 [oooooxx] [7]
5 [xxxxx] [8]
6 [xxoooo] [9]
7 [ ]
8 [ ]
9 [ ]
10 [ ]
11 [ ]
12 [ ]
13 [ ]
14 [ ]
15 [ ]

[ZZZZZZ]

WORD CONVERTOR INPUT LAYOUTS (OPTIONS)

Columns 1 - 6	Columns 7 on ⟶		
OPTION	1 = encode 2 = decode 2,	words/ record 13,	read next deck 0 = yes O 1 = no
Mask oooo xo	Word No. 7		
ZZZZZZ			

Card 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15

Omit any mask cards which are not used.
All fields from col. 7 on should be separated by commas.

WORD CONVERTOR INPUT (DECODING)

Card no.	Columns 1 - 6	Column 7 on All fields from col. 7 on are separated by commas.							
1	TABLES	0 *48,*	1 *0,*	2 *0,*	3 *1,*	4 *2,*	5 *3,*	6 *4,*	7 *5*
2	TABLES	8 *6,*	9 *7,*	10 *8,*	11 *9,*	12 *17,*	13 *18,*	14 *19,*	15 *20*
3	TABLES	16 *21,*	17 *22,*	18 *23,*	19 *24,*	20 *25,*	21 *33,*	22 *34,*	23 *35*
4	TABLES	24 *36,*	25 *37,*	26 *38,*	27 *39,*	28 *40,*	29 *41,*	30 *50,*	31 *51*
5	TABLES	32 *52,*	33 *53,*	34 *54,*	35 *55,*	36 *56,*	37 *57,*	38 *16,*	39 *44*
6	TABLES	40 *11,*	41 *12,*	42 *26,*	43 *27,*	44 *28,*	45 *32,*	46 *34,*	47 *35*
7	TABLES	48 *49,*	49 *58,*	50 *59,*	51 *60,*	52 *0,*	53 *0,*	54 *0,*	55 *0*
8	TABLES	56 *0,*	57 *0,*	58 *0,*	59 *0,*	60 *0,*	61 *0,*	62 *0,*	63 *0*

Output in this run was written on tape unit four. Since the select routine requires this file on tape unit two, the operator had to be notified to dial the unit to two.

Select Run

Statement of the Problem

TEST [PR number in columns 2-5]

IF [Q574, Q175, Z443, Z551] THEN TEST [Time Control in columns 17-19]

IF [704] THEN [write tape] OTHERWISE GO BACK TO INPUT.

Description

In setting up this run, the following forms are used: one initialization card form and as many selection cards forms as there are fields to be tested.

The initialization card form contains 3 parameter cards which are filled out in the following way:

Card 1 (LOCATE card) In Field 1 the starting address of our generated select program which is 2560_{10} or 5000_8. In field 2 of the card, the first word address of the input data is 1979_{10} or 3673_8.

Card 2 (TAPECD) Since the input is to come from the decoder, a 4 is placed for input tape unit in field 1. The action of the problem does not call for a subroutine, so a zero is placed in field 2. A report run will follow so a 1 is placed in field 3. The output is to be on tape 7, so this number is placed in field 4. No other tapes are used, so a zero is placed in field 5 to end the card.

Card 3 (the finish card) does not need to be filled in. Its identification in columns 1-6 is used to terminate the select generator.

Two selection cards, one for each test in the problem, are used. The first contains the information for the PR number test. Since 4 discreet values are to be selected, a 4 is placed in field 1.

Fields 2, 3, and 4 have zeros because no action is to be taken here. Field 5 also contains a zero, since it is necessary to test the next field to determine a selection.

If the PR number is not found, then further testing is unnecessary. Therefore, a "1" in field 6 takes the program back to input. Fields 7, 8, 9 will contain zeros since no action is needed. The data being in columns 2-5 requires only one mask and is the first word of the input. The "1" is placed in field 10. The remaining fields are left blank.

The mask card (2) is filled in with 4 X's in columns 2-5 and two zeros in columns 1 and 6. This mask will operate on the first word of the input data eliminating the first and last character.

Since the values are discreet, they are placed on the discreet value card. Only one card is necessary because only one mask is used. Note that zeros are used to fill in characters masked out by the mask.

The second selection card sets up the test for the operation code. There is only one number to be tested, so a 1 is placed in field 1. No subroutine is needed, so a zero is placed in field 2. Since the output is to go on tape 7 and contain 13 words per record, these numbers are placed in fields 3 and 4 respectively. A one in field 5 sends the program back to input. No negative action is needed.

A "1" and 3 zeros are placed in fields 6, 7, 8, and 9 respectively. The data being in columns 17-19 require two masks. These are in words 3 and 4. These numbers are placed in fields 10 and 11. The remaining fields are left blan

The mask card 2 is filled in with 3 X's in columns 5, 6, and 7. The columns 1-4 and 8-12 contain zeros. These masks will operate on the 3rd and 4th words of the input data eliminating the first 4 characters of word 3 and the last 5 of word 4.

Since the value is discreet, it is placed on the discreet value card. Two cards will now be needed. The first will contain 000070, and the second 400000 in columns 1-6 of the first two discreet value cards respectively.

The forms are now given to a key punch operator, who punches the IBM cards. These cards are inserted in their proper place in the select deck. The program is now ready to run as part of the system. After the select has completed its work, it will transfer control to the card reader to read in the report deck.

Card 1 *	Col. 7 on	
Col. 1-6	1	2
LOCATE	2560,	1979

Column annotations (vertical labels below Card 1):
- Identification
- Decimal starting location of generated select program.
- Decimal location of input data.

Card 2 *	1	2	3	4	5		
TAPECD	4,	0,	1,	7,	0		

Column annotations (vertical labels below Card 2):
- Identification
- 0=used as subroutine or no. of input tape unit.
- No. of subroutines used in generated select.
- 0=terminate run 1=read in another program from cards.
- Fields 4 on
- output tape unit nos. 0 will follow last tape unit no.

*All parameters are to be separated by commas.

Card 3**

FINISH

** This card is to follow the last select sequence.

Report Run

A report on the total 704 computer time used for PR's Q574, Q175, Z443, and Z551 for fiscal week 51 is desired. Using the output from the select run which is on unit 7 as an input to the report generator and completing the required form describing the format of the report from which parameter cards to the program can be punched, the desired report will be printed on tape 8. This output tape is then listed on the Type 720 printer under program control.

On the form, under Input Information, we fill in "7" for the input tape, "8" for the output tape, "1" for form size (we want the report printed on 14 3/4" x 11" paper), and "1" for page number which will put the page number in the upper right hand corner of the page. To determine the number of data lines per page, we must consider the number of title lines, footnotes and the spacing used. In the sample

1.

Field No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SELECT	4,	0,	0,	0,	0,	1,	0,	0,	0,	0,	1,				

Identification

No. of values/field
-2 for range

Decimal address of
hand coded subroutine
0 = no subroutine

Tape no. of output
tape. 0 = no tape
written.
Number of words to be
written on output
0 = no output tape
1   go back to input
0   continue to next
selection test

0 = no action
1 = back to input
decimal address of
subroutine
Tape no. of output tape
0 = no output tape
Number of words to be
written on output
0 = no output tape
0 = back to input
1 = continue to next
text
word no. on input tape
for first mask
word no. on input tape
for second mask

word no. on input tape
for third mask

word no. on input tape
for fourth mask
word no. on input tape
for fifth mask

word no. on input tape
 for sixth mask

---

2. Mask card start in column 1 go to 72
0 for characters to be omitted
X for characters that are to be used

POSITIVE   NEGATIVE

Col. 1   6   12   18   24   30   36   42   48   54   60   66   72

| oxxxxO | | | | | | | | | | | | |

3. Value Cards
a. range

Col. 1   6   12   18   24   30   36   42   48   52   60   66   72

lower range

upper range

b. discreet
value

Col. 1   2   3   4   5   6   7   8   9   10   11   12

value card rows 1–12

21

1.

Field No. 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SELECT	1,	0,	7,	13	1,	1,	0,	0,	0,	3, 4					

Identification

No. of values/field
-2 for range

Decimal address of
hand coded subroutine
0 = no subroutine

Tape no. of output
tape. 0 = no tape
written.
Number of words to be
written on output
0 = no output tape
1   go back to input
0   continue to next
selection test

0 = no action
1 = back to input
decimal address of
subroutine
Tape no. of output tape
0 = no output tape
Number of words to be
written on output
0 = no output tape
0 = back to input
1 = continue to next
text
word no. on input tape
for first mask
word no. on input tape
for second mask

word no. on input tape
for third mask

word no. on input tape
for fourth mask
word no. on input tape
for fifth mask

word no. on input tape
 for sixth mask

POSITIVE   NEGATIVE

2. Col. 1 6 12 18 24 30 36 42 48 54 60 66 72

0000XX X00000

3.   Value Cards
   a. range

Mask card start in column 1 go to 72
0 for characters to be omitted
X for characters that are to be used

Col. 1   6   12   18   24   30   36   42   48   52   60   66   72

upper range

lower range

Col. 1   6   12   18   24   30   36   42   48   52   60   66   72

   b. discreet
value

000070

000000

value

report, we use 9 title lines (blank lines are counted) and 2 footnote lines. The data lines are to be single spaced. Using a maximum of 60 lines per page, the number of data lines per page would be at the most 49. We will use "49" in the fifth block. The report shown, of course, is very brief so 49 lines were not used. This run does not follow a sort, so a "0" is used in block 6. In block 7, a "1" is used to obtain single spacing.

To lay out the format, the page headings are printed in the exact print position columns in which they are to be on the report. Each line is given an identification -- the first line "P1", the second "P2", etc. Two parameter cards are used for each line, print positions 1-60 are punched in the first card, and print positions 61-120 are punched in the second card (Line identification is punched in columns 61-62 of the second card).

On the data lines, we want to print the PR number, DPC number, checkout, production, error and total times. We place X's in the print positions in which this information is to be printed. Decimal points are placed in the positions in which they should appear on the report. There is only one data line on this report for each item on tape. It carries the identification "D1".

We want to print totals for all of the selected PR's at the end of the report. This will be described on a final line. Double spacing is desired before printing the final line. This is accomplished by putting "0" in print position 1 on the "F1" line.

If this report continued over several pages, we would want the footnote to appear at the bottom of each page. We would have a blank line after the last data line on each page which would be followed by the footnote. Two format lines are required to do this -- an "N1" line for the blank line and an "N2" line for the footnote.

The end of the format lines is marked by the "FORMAT" card.

To describe the source of data for the fields on the format lines, data line and total line information cards are required. There is one card prepared for each field on each line. Columns 1 and 2 are the same as the line identification, "D1". PR number is field 1, starting in print position 48 on the line, and the data is obtained from the field in the item on tape which starts in word 1, character 2, and extends for 4 characters. No zero elimination is desired, so "0" is used in field 6.

For the final line, "F1", we must prepare cards giving the source of the data to be totaled. "0" is used for the control level since it does not apply on final lines, the "checkout time total" is field "1", the print position for the least significant digit is "78", and the data is to be obtained from the field in the item on tape which starts in word 11, character 6, and runs for 4 characters.

After all of the source information cards, there must be an "ENDCRD".

All of these cards are placed in the order described above after the binary program deck.

The sample report follows.

INPUT INFORMATION

CD COL.	1 2 3 4 5 6 7 → Use Commas to Separate Fields						
	ID	INP. TAPE	OUT. TAPE	FORM 0 = SMALL 1 = LARGE	PAGE NO. 0 = DON'T PRINT 1 = PRINT	NO. OF DATA LINES PER PAGE	INP. FROM SORT 0 = NO 1 = YES	SPACING 1 = SINGLE 2 = DOUBLE
	REPORT	7,	8,	1,	1,	49,	0,	1

OUTPUT FORMAT

SUMMARY & FINAL LINE INFORMATION

DATA LINE INFORMATION

CD COL.	1. 2	7 ⟶ USE COMMAS TO SEPARATE FIELDS				
	LINE ID	FORMAT LINE FIELD	HIGH ORDER CHARACTER		NO. OF CHARACTERS IN FIELD	ZERO ELIM. 0 = NO 1 = YES
			PRINT NOS.	WORD NO.	CHAR. NO.		
	D1	1,	48,	1,	2,	4,	0
	D1	2,	59,	2,	1,	7,	0
	D1	3,	74,	11,	6,	4,	0
	D1	4,	88,	12,	5,	4,	0
	D1	5,	103,	11,	1,	4,	0
	D1	6,	114,	4,	3,	4,	0

CD COL.	1-2	7 ⟶ USE COMMAS TO SEPARATE FIELDS					
	LINE ID	CONTROL LEVEL	FORMAT LINE FIELD	LAST PRINT POS.	HIGH ORDER CHAR.		NO. OF CHARACTERS IN FIELD
					WORD NO.	CHAR. NO.	
	F1	0,	1,	78,	11,	6,	4
	F1	0,	2,	92,	12,	5,	4
	F1	0,	3,	107,	11,	1,	4
	F1	0,	4,	118,	4,	3,	4

CD. COL.	1-2	7 ⟶
	ENDCRD	

F I S C A L   W E E K   5 1

7 0 4   C O M P U T E R   U S A G E
F O R   S E L E C T E D   P R O G R A M   R E C O R D S

PR NO.	DPC NO.	CHECK OUT TIME	PRODUCTION TIME	ERROR TIME	TOTAL TIME
Q175	6Q.1.01	01.35	00.00	00.00	01.35
Q574	6B.2	00.66	00.00	00.00	00.66
Z443	2Z.4.01	00.38	01.22	00.00	01.60
Z551	2Z.3	00.00	00.11	00.00	00.11
	TOTAL	2.39	1.33	.00	3.72

NOTE   ALL TIMES ARE EXPRESSED IN HOURS.

Progress Is Our Most Important Product

GENERAL 🄖 ELECTRIC

Fort Wayne, February 18, 1957

Subject: 39 Frame Systems Project
          Wage Administration Study
          Scope and Boundary Report

OBJECTIVE:

The objective of this study is to outline the routines followed by the Wage
Administration function in the assignment of rates and codes, the reporting
of Wage information, and the evaluation of new jobs.

BOUNDARIES:

This study will deal with that part of the activities mentioned above which
is accomplished by the Wage Administration personnel in the General Purpose
Motor Department, with the exception of blanket wage adjustments and job
evaluation. In these two areas an attempt will be made to show the entire
process. That part which is a function of Central Wage Administration is not
intended to be covered in a detailed study.

EXCLUSIONS:

(a) Activities of the Payroll Office in processing engagements and transfers
     and the preparation of reports.

(b) Activities of the Employment Office in the engagement and transfer
     routines.

(c) Detailed activities of the Central Wage Administration Office in connection
     with a blanket wage adjustment.

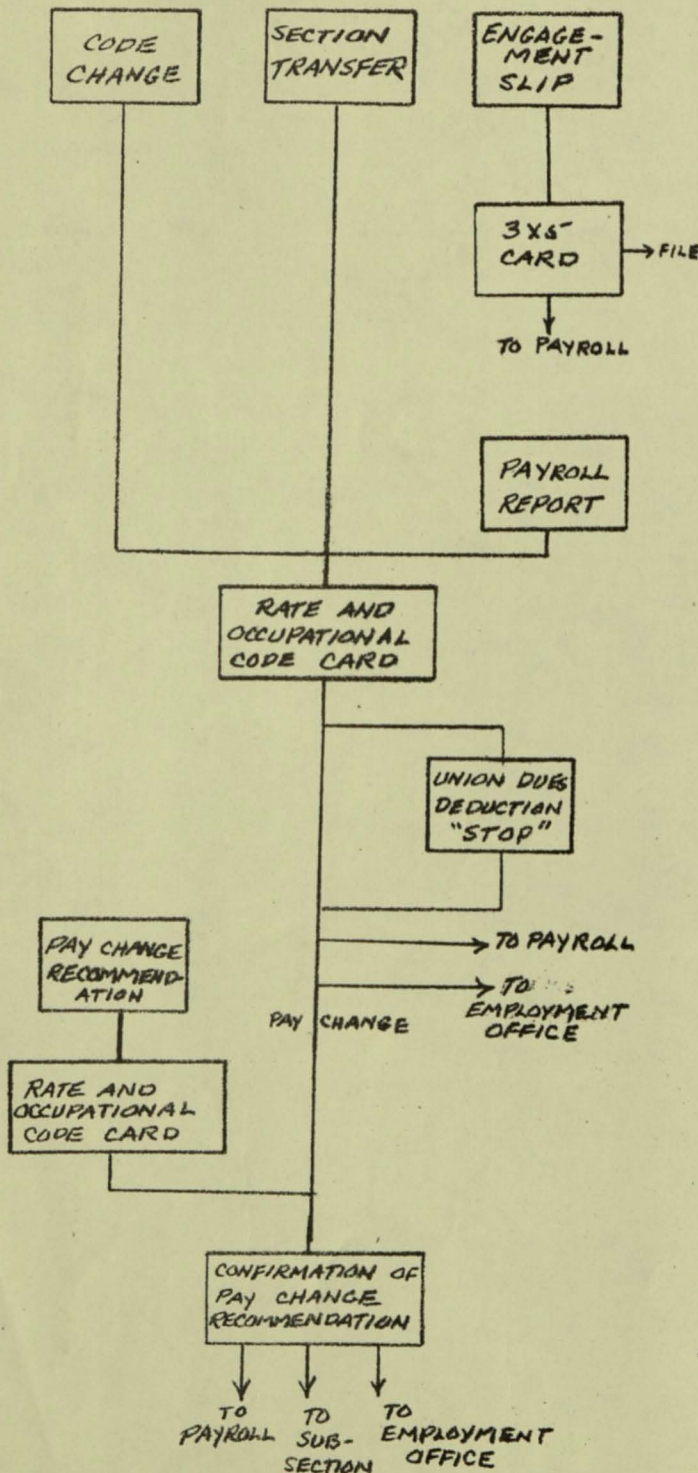(d) Analysis of forms or files which are a part of Central Wage Administration
     exclusively.

SCOPE:

(a) Checking of rates and codes on engagement slips and section transfers.

(b) Initiation of rate and occupational code cards and process of keeping
     these cards up to date.

(c) Payroll report, and the information which is obtained from it.

(d) Processing of information for employees assigned to daywork (or
     incentive) occupations.

(e) Changes of occupation within a section.

(f) Confirmation of pay change recommendations.

(g) Changes from Group A to Group B.

(h) Administration of a general increase (blanket wage adjustment).

(i) Activities followed in making a job evaluation and initiating a new
     code and job description.

(j) Checking average earnings cards for average earnings report.

EXHIBIT 5

SAMPLE
SUMMARY CHART

ENGAGEMENTS, TRANSFERS AND CHANGES IN PAY

CODE CHANGE

SECTION TRANSFER

ENGAGE-MENT SLIP

3 × 5 CARD → FILE

TO PAYROLL

PAYROLL REPORT

RATE AND OCCUPATIONAL CODE CARD

UNION DUES DEDUCTION "STOP"

PAY CHANGE RECOMMEND-ATION

→ TO PAYROLL

PAY CHANGE

→ TO EMPLOYMENT OFFICE

RATE AND OCCUPATIONAL CODE CARD

CONFIRMATION OF PAY CHANGE RECOMMENDATION

TO PAYROLL   TO SUB-SECTION   TO EMPLOYMENT OFFICE

CODE CHANGE NOTICE (FOR CHANGE OF OCCUPATION WITHIN A SUB-SECTION), SECTION TRANSFER, OR ENGAGEMENT OR RE-ENGAGEMENT SLIP (INCLUDES TRANSFERS FROM OTHER DEPARTMENTS) ARE CHECKED FOR CORRECT RATE AND CODE WHEN RECEIVED.

IN THE CASE OF AN ENGAGEMENT OR RE-ENGAGEMENT A 3×5 CARD IS USED TO RECORD RATE AND CODE WHILE THE ENGAGEMENT SLIP IS SENT TO PAYROLL.

AFTER PAYROLL REPORT IS RECEIVED AND PAY NUMBER IS VERIFIED, A RATE AND OCCUPATIONAL CODE CARD IS INITIATED AND RATE AND CODE ARE ENTERED ON IT.

IN THE OTHER TWO CASES, RATE AND CODE ARE ENTERED ON THE RATE AND OCCUPATIONAL CODE CARD WHICH IS ON FILE. REMOVALS, WHICH ALSO APPEAR ON THE PAYROLL REPORT, ARE RECORDED ON THE RATE AND OCCUPATIONAL CODE CARD.

IF CODE ENTRY CHANGES AN EMPLOYEE FROM ONE UNION "GROUP" TO THE OTHER A UNION DUES DEDUCTION "STOP" IS FILLED OUT AND SENT TO PAYROLL.
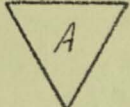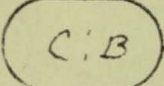
CODE CHANGE NOTICE IS SENT TO EMPLOYMENT OFFICE, SECTION TRANSFER IS SENT TO PAYROLL UNLESS A PAY CHANGE IS INVOLVED. IF A PAY CHANGE OCCURS ON A SECTION TRANSFER THE TRANSFER IS HELD FOR CONFIRMATION.

WHEN A PAY CHANGE RECOMMENDATION IS RECEIVED IT IS CHECKED AGAINST THE WAGE SCALE. IF IN ORDER, THE ENTRY IS MADE ON THE RATE AND OCCUPATIONAL CODE CARD.

CONFIRMATION OF PAY CHANGE RECOMMENDATION IS FILLED OUT FROM SECTION TRANSFERS AND PAY CHANGE RECOMMENDATIONS. CONFIRMATION IS SENT TO SUB-SECTION AND EMPLOYMENT OFFICE. SECTION TRANSFERS AND PAY CHANGE RECOMMENDATIONS ARE SENT TO PAYROLL

ENTRIES	MAIN LINE FLOW	EXITS	SECONDARY FLOW	RECORDS	RECORD OR FIELD		FIELDS	REMARKS
●	ENGAGEMENTS AND RE-ENGAGEMENTS ▽ A 1			ENGAGEMENT (OR RE-ENG) SLIP				RECEIVED FROM EMPLOYMENT OFFICE. THIS INCLUDES TRANSFERS FROM OTHER DEPARTMENTS
●	C;B ≠ = 2			ENGAGEMENT SLIP — ON	CODE, JOB RATE, AND ACTUAL RATE — COMP	WITH	CODE AND RATES ON WAGE SCALE	WAGE SCALE IS IN OCCUPATIONAL CODE BOOK
	3		⊟ — ON	ENGAGEMENT SLIP	INCORRECT ENTRY — DEL			THIS IS DISCUSSED WITH THE FOREMAN, USUALLY BY PHONE
	4		⊞ + ON	ENGAGEMENT SLIP	CORRECT ENTRY — INS	FROM	WAGE SCALE	
●	5	△ A TO EMPL. OFFICE		EMPLOYMENT OFFICE IS NOTIFIED, BY PHONE, OF THE CORRECTION.				
	⊞ + 6			3×5 CARD — ON	PAY NUMBER SECTION NO., EMPLOYEE'S NAME, DATE OF ENGAGE., CODE, AND RATE — INS	FROM	ENGAGEMENT SLIP	
●	⊞ + 7			ENGAGEMENT SLIP — ON	SIGNATURE OF WAGE ADMINISTRATOR — INS			
	◇ SP 8			ALL RECORDS — SEP				
●	(AM) ▽ 9			3×5 CARD — TO	FILE (DESK DRAWER)			
	▽ B			ORIG. ENGAGEMENT SLIP — TO	PAYROLL OFFICE			

Sym				Action	Object	Prep	Detail	Prep	Source	Notes
		△ C			COPY OF ENGAGEMENT SLIP	TO	SUB-SECTION BY WHICH EMPLOYED			
11										
▽ B					PAYROLL REPORT					A WEEKLY REPORT ON ADDITIONS AND DELETIONS TO THE PAYROLL
12										
◇ SR	NO FIND → IMP; FIND			SR	3X5 CARD FILE	BY	NAMES OF EMPLOYEES	FROM	PAYROLL REPORT	"NO FIND" WOULD INDICATE A CLERICAL ERROR.
13										
⬭ C:B	≠ ; =			ON	3X5 CARD	COMP	PAY NUMBER	WITH	PAY NO. ON PAYROLL REPORT	THIS IS DONE WITH EACH 3X5 CARD
14										
		□ −		ON	3X5 CARD	DEL	PAY NUMBER			
15										
		□ +		ON	3X5 CARD	INS	PAY NUMBER	FROM	PAYROLL REPORT	
16										
◇ SR	NO FIND; FIND			SR	INACTIVE RATE AND OCCUPATIONAL CODE CARD FILE	BY	EMPLOYEE'S NAME	FROM	PAYROLL REPORT	"NO FIND" INDICATES AN EMPLOYEE WHO HAS NEVER WORKED FOR THIS DEPT. BEFORE.
17										
		□ +		ON	RATE AND OCCUPATIONAL CODE CARD FILE	INS	ALL FIELDS	FROM	3X5 CARD	GROUP "A" CARD IF JOB REPRESENTED BY I.A.M. — GROUP "B" CARD IF REPRESENTED BY JOB
18										

SUBJECT CHARTED _WAGE ADMINISTRATION_

CHART BEGINS _ENGAGEMENT SLIP RECEIVED_

CHART ENDS _NEW JOB DESCRIPTION TO SUB-SECTION_

CHARTED BY _R. R. ANDERSON_

PAGE _1_ OF _8_

LAST EXIT # _____ C _____

LAST ENTRY # _ B _

FILE CODE _____

DATE _2/13/57_

③

ENTRIES	MAIN LINE FLOW	EXITS	SECONDARY FLOW		RECORDS		RECORD OR FIELD		FIELDS	REMARKS
●	[+]			ON	RATE AND OCCUPATIONAL CODE CARD	INS	DATE, RATE, CODE, AND OCCUPATION	FROM	3×5 CARD	
●	(C:B) = ≠ 2			ON	RATE AND OCCUPATIONAL CODE CARD	COMP	"GROUP" (A OR B) OF PRESENT JOB	WITH	"GROUP" (A OR B) OF PREVIOUS JOB (MOST RECENT)	
	[+] 3			ON	UNION DUES DEDUCTION STOP CARD	INS	ALL FIELDS	FROM	RATE AND OCCUPATIONAL CODE CARD	
	[+] 4			IN	UNION DUES DEDUCTION BOOK	INS	ALL FIELDS	FROM	UNION DUES DEDUCTION STOP CARD	
●	⬦ SP PAYROLL REPORT 5			SEP	PAYROLL REPORT	FROM	ALL OTHER RECORDS			
	6	(AM) ▽			RATE AND OCCUPATIONAL CODE CARD	TO	ACTIVE R.&O. CODE CARD FILE	BY	SECTION, THEN PAY NUMBER	
●	7	(AM) ▽			3×5 CARD	TO	FILE (DESK DRAWER)			
	8	▽ D			UNION DUES DEDUCTION STOP CARD	TO	PAYROLL OFFICE			
●	(C:B) = > 9			ON	PAYROLL REPORT	COMP	NO. OF REMOVALS	WITH	O	
		(AM) △X			PAYROLL REPORT	TO	PAYROLL REPORT FILE			

Symbol				Verb	Object	Prep		Prep		Notes
SR (diamond) — NO FIND / FIND — 11				SR	ACTIVE RATE AND OCCUPATIONAL CODE CARD FILE	BY	SECTION AND PAY NUMBER	FROM	PAYROLL REPORT	THIS IS DONE FOR EACH REMOVAL
+ (square) — 12				ON	RATE AND OCCUPATIONAL CODE CARD	INS	DATE OF REMOVAL	FROM	PAYROLL REPORT	
SP (diamond) — 13				SEP	R. & O. CODE CARD	FROM	PAYROLL REPORT			
AM (circle) — 14					R.&O CODE CARD	TO	INACTIVE R. & O. CODE CARD FILE	BY	EMPLOYEE'S NAME	
AM (circle) — 15					PAYROLL REPORT	TO	PAYROLL REPORT FILE			
SECTION TRANSFERS — 16										
C (triangle) — 17					SECTION TRANSFER					RECEIVED FROM EMPLOYMENT OFFICE
SECTION TRANSFER HANDLED SAME AS ENGAGEMENT SLIP PAGE 1, LINES 2,3,4,&5. — 18										

LIST OF EXITS - WAGE ADMINISTRATION STUDY

(a) Employment Office is notified, by phone, of a correction in code or rate on an engagement slip, made by the specialist - Wage Administration.

(b) Engagement slip (original) is sent to the Payroll Office, after approval of rate.

(c) One copy of the engagement slip is sent to the sub-section which is employing, after approval of rate.

(d) Union dues deduction (stop) card is sent to Payroll Office after completion.

(e) One copy of section transfer is sent to sub-section to which employee is transferred after approval of rate.

(f) Same as "d" above.

(g) Section transfer (original) is sent to Payroll Office after rate is approved.

(h) Information for employees assigned to daywork (or incentive) occupations is returned to section in which it originated after approval.

(i) Code change notice is sent to Employment Office after being checked.

(j) Confirmation of pay change (original and one copy) sent to sub-section involved.

(k) One copy confirmation of pay change is sent to Employment Office.

(l) All pay change recommendations and section transfers are sent to Payroll Office.

(m) Same as "d" above.

(n) Same as "i" above.

(o) Average earnings cards which have errors are returned to Payroll Office after correct entries have been penciled in.

(p) Average earnings cards which are correct are returned to the Payroll Office after being checked.

(q) Blanket wage rate adjustment sheet (original) and all adjustment slips are sent to the Payroll Office.

(r) Two copies blanket wage rate adjustment sheet are sent to each sub-section involved.

(s) One copy each blanket wage rate adjustment sheet is sent to Employment Office.

(t) 5x8 card containing job description is sent to sub-section where job is located.

GENERAL ELECTRIC COMPANY

MISSILE AND SPACE VEHICLE DEPARTMENT

PHILADELPHIA, PENNSYLVANIA

MECHANIZED RELIABILITY DATA SYSTEM

ENGINEERING COMPUTER
USER SYMPOSIUM
MAY 20, 1959

PREPARED BY
JOSEPH C. GENNETT, FUNCTION LEADER
TECHNICAL DATA SYSTEMS & METHODS
DATA PROCESSING & COMPUTATIONS

MECHANIZED RELIABILITY DATA SYSTEM

INTRODUCTION

The scope of the Mechanized Data System described here includes information pretaining to the prediction of the functional capabilities of materials, processes, and devices (used in our products), extending from the raw materials used, through Vendor and Manufacturing processes, into performance under environmental stresses, and finally the operational application-flight. Because of the complexity and magnitude of these requirements, every effort has been made to insure consistently complete results which facilitate maximum integration of data results with minimum communication effort.

Since presently our's is, overall, a research and development activity, we must deal on a day to day basis with a multitude of design changes, which have an impact on nearly every departmental function. We are attempting, therefore, to use electronic data processing speeds to disseminate to all quarters the story of the current status and where possible, the forecasted status of our products. We have, furthermore, installed and are implementing an effective communication network to supply an integration factor to the dissemination of required information to and from the customer, field sites and other allied facilities; utilizing this information as inputs into other electronic data processing systems which will supply both engineering and management with an integrated picture of decision-making factors.

The proper integration of Mechanized accumulated data with Space Vehicle development results in rapid and reliable progress because experimental and operational test data are available for immediate regenerative feedback, for analysis, and for equipment prediction purposes.

MECHANIZED RELIABILITY DATA SYSTEM

A Mechanized System permits a wealth of data to be accumulated, analyzed and processed, at electronic speeds, in order to provide a number of reports, both historical and analytical in nature. It may be advantageous to indicate here that high speed computer techniques, such as those developed at M.S.V.D, not only permit timely reporting and analysis but also allows for the storage,on Master Magnetic Tape files, all data generated;and thereby provides an integrated and highly versatile system basic to the production of a large number of other allied reports such as;the Missile Systems Log and establishing criteria for Scientific Spare Parts Provisioning.

DEFINITIONS

Since the definition of a "Mechanized Data System" has been broadly covered in the " Introduction" section of this paper; it now remains for us to define"Reliability" while correlating the meaning of a Mechanized System.

One accepted and simplified definition of Reliability is-"predicting how well a unit will operate with respect to its designed function."

Within the scope of this definition the value of testing and the regenerative effect of feedback of test results cannot be too strongly emphasized. Without such feedback there is no reason to believe that our hundreth product will be better than our fiftieth-if as good. Simultaneously, without such empirical evidence we have little hope of predicting how well the one hundred and first product will operate, with any degree of confidence. To obtain this continual regenerative feedback from the various testing programs into development with minimal program delay, data and data analysis must be accurate, complete, easily accessible and quickly available. To assure the aforementioned qualifications, high speed electronic equipment is being utilized within the Mechanized Reliability Data System. Needed data emanating from Vendor sites, Test and Inspection operations, and field and flight facilities are rapidly analyzed and processed on the IBM 704 high speed computer.

MECHANIZED RELIABILITY DATA SYSTEM

DEFINITIONS (CONTINUED)

Reliability paramaters are programmed and generate significant outputs in the form of Failure Rates, Mean-Time to Failure and Reliability Bounds, and are rapidly disseminated to Design, Manufacturing, Production, Testing and other pertinent operations which have the need to know for purposes of corrective and/or other types of action.

A communication link, used as a medium for the transmittal of information between geographically separated operations, is also fundamental to our feedback program, and by extension to the Mechanized Reliability Data System. The nature of the equipment utilized not only provides for minimizing equipment at remote locations but also allows for a great degree of flexibility. It will also provide for integration of other department of defense facilities related to our current program. Bi-lateral exchange of logistics, test and inspection reports and reliability data, on a real-time basis, provides for broad effective Management control within these operations. In addition, such facilities will clearly define procurement channels and will expedite procurement and dissemination of Management data.

New techniques in various stages of installation for purposes of rapid accumulation of required input include sophisticated data-logging equipment which automatically proffers inputs into high speed electronic data processing machinery without the fear of "human error" elements intervening.

PROGRAM INPUTS

In order to predict how well a unit will operate with respect to its designed function the Mechanized Reliability Data System must first spell out required program inputs. These inputs are secured:

    (1) From various testing areas such as: Vendor sites, In-House Labs, Field and Flight facilities.

    (2) At various levels of test such as: component, sub-assembly and system.

    (3) Over various types of testing such as: qualification, acceptance, requalification and cycle type tests.

MECHANIZED RELIABILITY DATA SYSTEM

PROGRAM INPUTS

The method used for securing the required input is divided into two Major Categories: (1) <u>Transmission</u> of data between geographically separated operations and (2) Collection of data at the <u>Source.</u>

(1) The transmission of data is currently accomplished by means of a Friden Teledata System. This Transceiver is used on both ends of a communications circuit, along with telegraph lines, telephone circuits, and/or Microwave systems. It can be used to transmit and receive simulataneously (duplex) and provides a stop upon detection of an error. These units are designed to handle 5,6,7,or 8 channel paper tapes. In operation, the transmitting end loads the tape to be read and telephones the receiving end. The receiving end loads paper tape into the receiver on the Teledata unit. The tape read switch is thrown on both ends to start the transmission. Upon detection of an error, a light is illuminated. On the transmitting end, the tape is pulled back to the last end-of-line code (8 channel hole only); the receiving end backs up to the same hole and depresses "Tape Feed" which punches delete codes into the incorrect data. The transmission of the line is then repeated.

The Teledata unit is normally operated with tapes produced in Flexowriters as by-products of a normal typing operation. However, adding machines and card to paper tape converters and similar equipment can also provide such tapes.

The Transceiver provides a means of transmitting from 10 to 30 cards per minute over 60, 75, or 100 words per minute telegraph lines or over telephone lines. At present all paper tapes received over the subject link are automatically converted to cards(on an IBM#047) and are then converted to Magnetic tape (on an IBM#714) as direct input to the IBM #704 computer.

MECHANIZED RELIABILITY DATA SYSTEM

PROGRAM INPUTS (continued)

(2) Source Mechanization of data has taken on the proportions of an
Integrated Universal Component Tester. This interesting and most versatile equipment
was designed and developed by our own M.S.V.D. equipment engineers and is primarily
an item of quality assurance test equipment. The I.U.C.T. plays an important role
in the rapid and reliable accumulation of data needed in Reliability predictions.
The objective here was to develope a test system that would measure and evaluate
product conformance to applicable specifications. The design expectations of the
equipment are to expeditiously and accurately stress, and measure any, or all, of
the Missile and Space Vehicle Departments products from the simplest component to
the most complex system.

Basically, the design concept of the I.U.C.T. employs punched-tape
programming of a complete test cycle for the component under test.

The previous sentence is a real healthly mouthful and as such deserves more
detailed analysis.

The phrase-"test cycle" is defined as the complete and integrated control,
distribution, and measurement of all electrical stimuli necessary to operate the
Component under test; and the integrated control, distribution, measurement, analysis,
decision capability and read-out of the resulting output voltages and/or signals.

"Punched-tape programming" of the test cycle is defined as the capability
to automate and integrate all of the required stimuli and outputs in such a manner
that they are supplied, delivered, analyzed and read-out in the proper sequence, and
at the proper time.

A vast number of advantages are realized by the utilization of the I.U.C.T.
These advantages include, but are not limited to, the following:

MECHANIZED RELIABILITY DATA SYSTEM

PROGRAM INPUTS (continued)

(1) <u>Test time is reduced</u>- interconnection, set-up, and monitoring of test
equipment is automated.

(2) <u>Operating time is controlled-</u> operating time is minimzed by programmed
operation, operating time is recorded automatically(This time is the very core of the
Reliability program.)

(3) <u>Human error is eliminated</u>- Automatic sequencing eliminates chance of
erroneous application of signals. Automatic readout ensures valid information.

(4) <u>Data Processing Simplified-</u> The punched tape record can be fed directley
into existing IBM data processing equipment without manual transcription.

DATA PROCESSING TECHNIQUES

The techniques and equipment utilized in the processing of the Reliability
Data are indicated in great detail in a manual entitled " Mechanized Reliability Data
System". This manual was co-authored by the writer of this paper and is presently
available in the Technical Information Series (No. R59SD325). Consequently, the
discussion of Data Processing Techniques needed to add coherence to this paper will
be limited to the most generalized facts.   Positing the fact that the necessary
data inputs have been collected either <u>via</u> the teledata system or source data
mechanization system, as described previously, these data inputs are then translated to
Magnetic tapes utilizing the IBM #714. The magnetic tapes containing the raw input
data are then fed into the IBM#704 main frame. Here the data is introduced to the
computer program which directs the processing of the raw input data. Sorting, merging,
summarizing and totalling are accomplished as per specifications established by output
requirements.

Also built into the computer program are such necessary features as Table
Look-Up routines(which allow for sequence checking, checks for completeness and accuracy
of the data) and Statistical Formulae(needed for Reliability Calculations).

MECHANIZED RELIABILITY DATA SYSTEM

PROGRAM OUTPUTS:

The basic reports furnished within the framework of the Mechanized Reliability Data System include inception-to-date and monthly reports on the "Totals of Test Time, Cycles and Failures" and "Equipment Reliability Status Reports."

The function of the report on "Totals of Test Time, Cycles and Failures" is to give a picture of the test time accumulated, the value of the test conducted, and the environmental stresses to which the unit has been subjected. The number of failures that may have occured at any level, and during functional and environmental tests, are summarized and counted and then utilized to predict the units' reliability. The format of this report presents the data necessary to predict the reliability of:

(A) An individual component by individual environment.

(B) A type of component by individual environment.

(C) An individual component by combined environments.

(D) A type of component by combined environments.

The function of the "Equipment Reliability Status Report" is twofold:

(1) To indicate the current Reliability of our products(within 50% and 95% confidence levels) while showing a breakdown of measured results through specific environments and by either Qualification or Acceptance type testing. The overall Reliability is simulataneously indicated by taking the mean-average of the same measured results through all environments and over both qualification and acceptance type testing.

(2) To predict the Reliability of our products by predicting the Failure Rates, Mean-Time-To- Failure, Upper Bounds through specified environmental stresses, and then the overall operational Reliability.

MECHANIZED RELIABILITY DATA SYSTEM

CONCLUSION

A Research and Development program would be unnecessary if we could put 100% confidence in our theories. Test requirements are designed to provide data from which we can judge the validity of our theories, make corrections if necessary, and develope new theories. Our data analysis is dependent primarily upon comparison of measured and derived data against theoretically calculated measurements for the same conditions. To perform such analysis, accumulated data must be accurate and in a form compatible for comparison with the theoretical results. For progress to be our most important product, as the G.E. Motto goes, data derived pertinent to the functional capabilities of our products must be correlated in such a way as to permit the highest degree of confidence to be placed in the predictability of our products. This, in essence, is the ultimate objective of the Mechanized Reliability Data System.

$$\left\{ \left[(A+B)\,(CD) + E \right] \left[(F+G)\,\overline{H} \right] \right\} \left\{ (JK + LM + \overline{N}\,\overline{P}) \right\}$$

the general electric GE *250*

INFORMATION
SEARCHING
SELECTOR

TO MEET THE DEMANDS FOR 〉 **rapid**
accurate
economic

selection and retrieval of desired technical
information from extensive files and libraries

the GE 250

information searching selector

WHAT IT IS:

The GE 250 Information Searching Selector is a data processing syst[e] specifically designed to provide rapid inquiry and selection from la[r] data files.

In its simplest form, the Information Searching Selector provides:
1. Storage of the information
2. Storage of the search questions
3. Means for comparing 1. and 2., detecting desired informati[on] and recording the result

The information file is stored on magnetic tape which provides a compact record with unlimited expansion.

Search questions are stored in the memory of the Selector.

Whenever search questions are satisfied, answers are recorded.

HOW IT OPERATES:

Up to ten inquiries may be prepared on punched paper tape and entered into the Selector's main memory for simultaneous processing. Successive reels of magnetic tape file are searched at the rate of 15,000 characters per second for satisfaction of any or all of the ten inquiries. Each tape may contain six million or more characters.

A printed text or identifying information is provided in answer to all selected questions and the search criteria they fulfill. If desired, partial satisfaction of any search question may be obtained.

WHAT IT DOES:

- Retrieves selected information from a large storage file
- Permits immediate and efficient use of recorded knowledge
- Answers questions through high-speed electronic searching
- Correlates scattered information in complex files
- Reduces costs of file preparation and searching
- Simplifies updating of information with new material — simplifies elimination of obsolete information.

IT CAN SERVE YOU:

if you need to retrieve information quickly and economically from vast files of data as found in:

| Industry	Government	Professions
Chemicals	Patents	Law
Metals	Military	Medicine
Petroleums	Personnel	Applied Research
Pharmaceuticals	Intelligence	Libraries
	Law Enforcement	
	Census	

The first GE 250 Information Searching Selector will be delivered to the Center for Documentation and Communications Research at Western Reserve University. It will be used to accelerate the abstracting service of a metals information center now in operation, as well as to facilitate further effort into other documentation and library research — including language translation.

DATA PROCESSING

GENERAL ELECTRIC — AUTOMATED BY GENERAL ELECTRIC

features of the GE *250*

information searching selector

■ HIGH SPEED: automatically reviews and compares 15,000 characters per second — several thousand abstracts per minute

■ MULTIPLE SEARCH: up to *TEN* unrelated inquiries can be searched simultaneously

■ EXPANSIBILITY: your growing requirements can be accommodated with a wide variety of additional equipment:

— additional magnetic tape units

— additional search requirement storage units

— high speed card readers

— high speed perforated tape reader

— card reader and punch unit

— additional buffer storage units

— high speed printer

■ SEARCH EFFICIENCY: can handle complicated search inquiries — provides extreme accuracy of retrieval

■ ECONOMICAL: designed to provide operations at low cost per unit of information
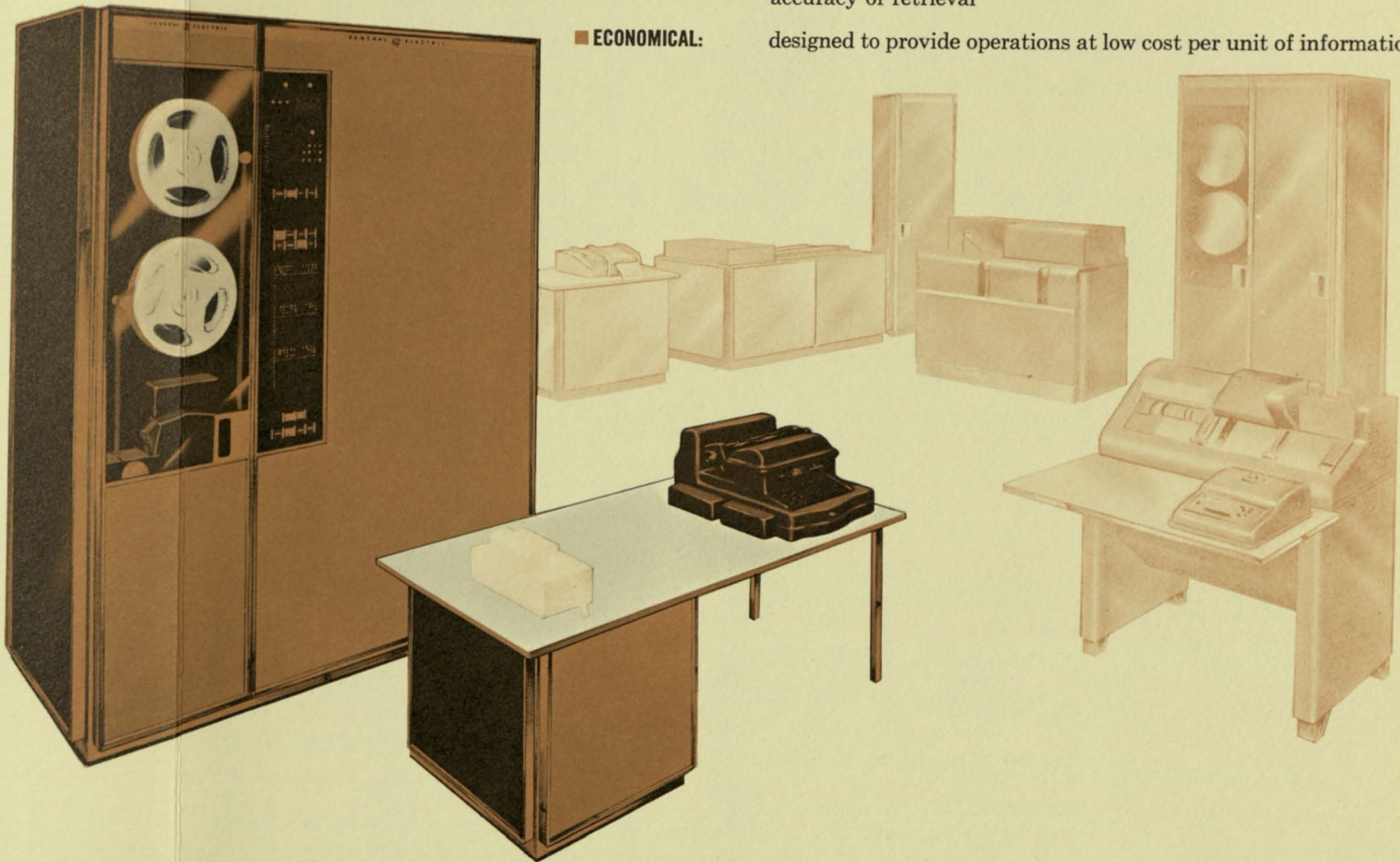
■ COMPACT   **■ EASY TO INSTALL**   **■ LOW POWER CONSUMPTION**

■ EASE OF OPERATION   **■ FULLY TRANSISTORIZED**

The GE *250* Information Searching Selector can provide operational and cost benefits with any indexing, classifying or coding system — even simple English notation. Professional assistance will be provided for developing systems and adapting well-tested procedures to assure that customers achieve optimum benefits in the shortest possible time.
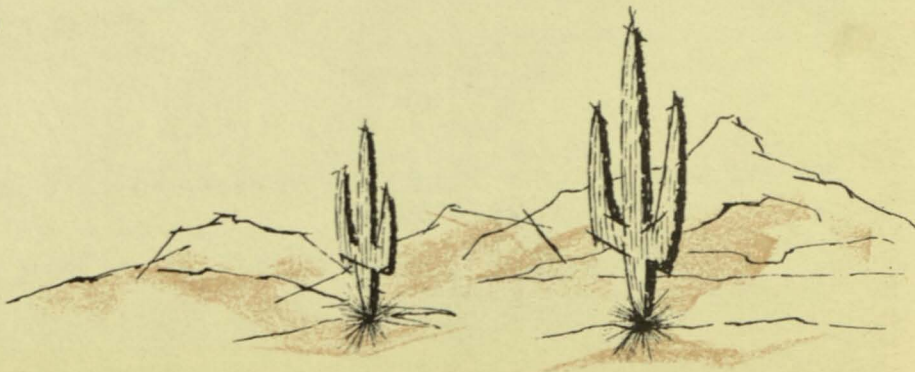
For additional details on the GE 250 Information Searching Selector, contact the General Electric Computer Department, Deer Valley Park, Phoenix, Arizona.

Progress Is Our Most Important Product

GENERAL 🌀 ELECTRIC

Computer Department, Phoenix, Arizona

epic

electronic
patient
information
control system

GENERAL ELECTRIC

X-RAY DEPARTMENT
MILWAUKEE, WISCONSIN

Information gathered on the digital recorders will then be sent to the central processor for data reduction and analysis. The central processor will then perform a preliminary data processing operation which will consist of (1) putting the information into the proper scale or calibration, (2) reorganizing the information; first, by patient; second, by function and third, by time, and (3) rerecording the information onto each patient's current medical record file in the proper sequence.

At this point two types of computer programs will be available for further analysis of this data. The first type will be general data research programs such as time trend analysis, simple, multiple, cross and auto-correlations, response analysis, event search and tabulation routines, etc. The second type of program will be more specific routines designed to answer doctors' specific questions about the data and to display the data for him in a variety of forms. Examples of these more specific programs are (1) cumulative doses of a medication shown as a function of time, (2) medication or treatment events shown on a time plot along with some selected physiological variables, (3) smoothed or averaged or condensed series of measurements, (4) expected future measurements based on extrapolated trends. Many others will be defined as further experience is gained in use of the system.

These routines will be so programmed that the questions or requests made by the doctor or medical researcher will be phrased in English language statements or questions. No programming or computer knowledge will be required on the part of the doctor.

Plan For

ELECTRONIC PATIENT INFORMATION CONTROL

SYSTEM

Prepared By

General Electric Company
X-Ray Department
4855 Electric Avenue
Milwaukee 1, Wisconsin

September 15, 1961

CONTENTS   Page

INTRODUCTION

Tremendous strides have been made in the last few decades in improved medical care. Much of this is the result of newly discovered drugs and other treatments. Much also has resulted from newly discovered methods of collecting and analyzing medical information. It is the intention of this study to consider the additional improvements in medical care which can be made by applying electronic techniques of collection, transmission, storage, analysis and display to medical information. The consideration is here restricted to the application of these techniques within a hospital, the prime source of improved medical care. The ultimate in an Electronic Patient Information Control system would, at least, perform the following functions:

An Electronic Patient Information Control system would collect information on the patient from a number of sources: medical histories, laboratory tests, physiological sensors attached to the patient, doctors' and nurses' observations, etc. The system would transmit this information to a central processor to be analyzed, compared with previous information on that patient or on other samples of patients with similar conditions, and compared with potential diagnoses hypothesized by the doctor or by the central processor itself. The result would be information useful for diagnostic purposes and recommendations for additional tests or measurements. With further advances

expected in medical science the system will also be able to test the effect of various treatments on a mathematical model of the patient.

This ultimate EPIC system is only a few years away. However, it depends on a great deal of preliminary information collection and analysis.

However, there are a number of logical steps leading toward the ultimate system which can themselves provide significant assistance to the medical profession. The remainder of this study is devoted to suggesting a program which leads toward this ultimate system in an orderly fashion. This program also provides this growth pattern in such a manner that the operating cost is reduced sufficiently so that each addition is itself economically justifiable.

There are, of course, any number of directions from which to approach the ultimate system. It is felt that the means proposed is the most desirable in that it achieves immediate advantages which are increased as additions are made to the system. It is expected that other complementary courses will be followed simultaneously by other organizations. Every attempt will be made to coordinate with such other programs so that the ultimate may be approached sooner.

Part 2

GROWTH PATTERN

GROWTH PATTERN

Introduction

There are any number of approaches to Patient Information Control systems. They all have the same ultimate purpose which might be expressed in general terms as better medical care. What distinguishes these approaches one from another is their shorter term or intermediate objectives and their field of application.

This particular approach has as its field of application the hospital.- more specifically, the average sized short term, general hospital. It has as its primary purpose the improved medical care of the patients being treated in that hospital. This means improved knowledge of patient condition, improved quality of treatments and tests available, and improved control of treatments and tests administered to the patient.

This program also has a number of secondary objectives. Advances in the general field of medical knowledge is one of these. In many respects the demonstration of feasibility established by applying this system to a hospital is in itself an advance in the art of medicine. In addition, this system can provide more specific advances by its ability to perform measurements and data analysis of controlled tests on new equipment, treatments, procedures, etc.

Another objective of this program was improved economics of

operation. In addition to the improved care aspects, this improved care must be provided at no increase in operating costs. Some other objectives are improved administrative control of the operations of the hospital, thus permitting better management from a number of points of view. Another objective is improvements in the flexibility of the hospital to adapt to changes in operating parameters such as increased size of the total operation or of any department within the operation.

In the establishment of an approach for growth of any long range program, the most important single factor is practicability. Programs involving the most perfect theories and the most accepted goals have failed because of the impracticability of some key element. The successful program considers all of the factors but puts special emphasis on the factors where practicability is important.

The growth pattern of an Electronic Patient Information Control system as outlined in this section puts great weight on the practical considerations. In all cases the approach uses concepts and equipment which are feasible today. No technological breakthroughs are required at any point in the program.

A great deal of data collection and analysis will be required in order to put clinical significance on each step and to define the specific information to be collected and analyzed in subsequent steps. However, the system has been so laid out that the necessary analytical tools and

- 4 -

equipment are available at each step to perform these functions with
ease and accuracy.

Another factor which has been given great consideration in the es-
tablishment of this growth pattern is the advantage accruing to the
user, not only as the ultimate system is approached but at every step
along the way. Such advantages are not restricted to improved medi-
cal care but also cover such mundane matters as economics and oper-
ational simplicity. The growth pattern has been designed in such a
manner that at every step of the program the added cost of equipment
and specially trained personnel is at least offset by the reduced cost
of operations.

Before proceeding with a description of this approach, it must be
pointed out that this is a general approach to the ultimate EPIC system.
As such it would be undesirable to treat each and every step in the
program as being fixed. Changes in number timing and sequence of
the detailed steps must be made as desirable and necessary.

The general plan is a three-phase approach toward the ultimate EPIC
system. The first phase includes a basic information processor and
some elementary applications, namely a Doctors' Orders Processor
and Alarm and Display Monitors for acutely ill patients. This first
phase would be put into operation as soon as possible.

The second phase covers a gradual buildup of information included

in the system accompanied by a parallel and expanding program of data reduction, analysis and presentation. At the conclusion of the second phase, all of the information which is generated on every patient in the hospital will be included in the system and will be subject to analysis. The second phase will begin after the first has been completed and is operating smoothly. The second phase will span a period of approximately three years.

The third phase covers an advanced information processing system. The basic information processor installed in phase one will continue to be the central information processor with added capabilities. This third phase will be built around analysis of complete patient information. It must be recognized that "complete" patient information will be limited to information gained only while the patient was in that hospital. Eventually other sources of information will be factored into the system. (Other hospitals, private doctors, clinics, military services, etc.) This third phase will tie in historical patient information with real time patient information to produce alarm and action signals with added clinical significance. The third phase will start shortly after the conclusion of the second phase and will continue into the undefined future.

Ultimate EPIC System

Additional Examples of Outputs

Diagnostic Data Research
Basic Action Recommendations
Controlled Test Analysis
Legal Records Research
Clinical Data Research
Accreditation and Licensure Data
Clinical Performance Reports
Special Condition Summaries
Case Summaries
Schedules
Patient Treatment Summaries
Work Summaries
Work Orders

Step 14 Information Feedback
Step 13- Patient Monitoring Computer
Step 11- Data Search & Retrieval Program
Step 7- Recording of all Patients
Step 4- Digital Recording
Step 2 Alarm Monitors
Step 3 Display Monitors

Step 15 Diagnostic Tool
Step 12- Electronic Record Storage
Step 10 Textual Reports
Step 9- Tabular Information Phase II
Step 8- Laboratory Instruments Recording
Step 6- Tabular Information Phase I
Step 5- Positive Patient ID
Step 1- Doctor's Order Processing

BASIC MEDICAL DATA PROCESSOR

Advanced Processor Phase
Input Growth Phase
Basic Processor Phase

Physiological Monitoring | Patient Information Processing | SPECIAL

1970 · 1969 · 1968 · 1967 · 1966 · 1965 · 1964 · 1963

ELECTRONIC PATIENT INFORMATION CONTROL

Step 1 - Doctor's Orders Processing

One of the most critical areas of patient information control is con-
cerned with the carrying out of doctors' orders by hospital personnel.
These orders are usually written by the doctor for the nurse to review
and expedite. A great deal of error derives from misinterpretation
and inadequate checking of these orders. It also occupies a tremendous.
amount of nursing time which could be better spent in direct patient
care.

The system proposed would have the doctor fill out his orders on a
preprinted form which would be sent to a central data processing in-
stallation. The data processor would then check the orders for com-
patibility with patient condition and standing instructions, and would
issue the orders to the various work stations (nursing stations, diet
kitchen, pharmacy, laboratory, X-ray department, etc.) at the time
a specific element of work is required. The accomplished work order
would be returned to the central processor with the fact of accomplish-
ment or the reason for non-accomplishment.

Such a unit can improve patient care both by more careful checking
and recording of what treatment the patient does and does not receive,
and also by increasing the amount of available nursing time by as much
as 20%. The central data processor also forms the basic unit for pro-
cessing all of the additional medical information collected in later steps.

Step 2 - Alarm Monitor

Where the condition of a number of patients must be intensively moni-
tored over an extended period of time, such as in intensive care units
and recovery rooms, there are two factors which make it highly desir-
able to perform this function with as much automatic measurement and
analysis as feasible. The first factor is that the automatic analysis
permits the doctor to define dangerous patient conditions directly and
have these dangerous conditions reported on a completely objective
basis. The second, and most important, reason is that the automatic
device can perform this measurement and analysis frequently or even
continuously for long periods of time with no danger of lapses due to
fatigue or boredom.

The primary function of the alarm monitor will be the generation
of alarm signals which have been analyzed and annunciated in accord-
ance with the doctor's instructions. In addition to the alarm signals,
records and displays are also generated as required.

Step 3 - Display Monitor   Spring 1963

In addition to the Alarm Monitors described in Step 2 there are cases,
namely in operating rooms, where the measurements made on the pa-
tient must be presented directly to the doctor who will then perform
any required analysis himself. The basic purpose of the Display Moni-
tor is to present this information to the doctor or team of doctors in

- 9 -

the most readable and understandable form. It also has the capability

of recording this information.

At the conclusion of Step 3 the hospital will have an elementary sys-

tem for collecting information on treatments and tests made on the pa-

tient (Step 1), a basic information processor which can be readily ex-

panded (Step 1), and a system for collecting physiological data on the

most critically ill patients in the hospital (Steps 2 and 3). The next

logical step is to provide a means for correlating and otherwise analyz-

ing this treatment, test and physiological information.

The basic information processor can perform the required analysis

without alteration. What remains is to convert the information to the

format required by the information processor. This is an analog to

digital conversion system operating on the output of the physiological

monitoring equipment. Information on treatments and tests performed

is already in the proper format from Step 1. After analog to digital

conversion all of the information is assembled on magnetic tape which

can be searched, analyzed and researched as desired.

Some of this analysis has almost immediate application to improved

patient care; for example, correlations between treatments and physio-

logical measurements showing the rate and extent of response of the

patient to the particular treatment provided. Another example might

be the quantitative comparison over a period of time of measurements

such as cardiac or respiratory arrhythmias.

Much more of this analysis has more general and longer term value

to improved patient care in its ability to provide additional information

for medical researchers.   For example, in the evaluation of a new

drug or other treatment it is often desirable to make detailed obser-

vations of its effect on a number of patients. Analysis of this type of

information would also find utility in determining the clinical signifi-

cance of new types of physiological sensors as calibrated against exist-

ing types on a number of patients.

Analysis of this data will be of most significant value in fairly basic

studies such as multiple correlations among the various measurements

and the establishment of standards for measured recovery patterns

from different types of treatments.

Step 5 - Positive Patient Identification   Late 1963

Before proceeding with any expansion of the scope of patient infor-

mation, some consolidation of the achieved gains must be undertaken.

The Doctor's Orders Processor - Step 1, has provided a means for

the medical staff to maintain close supervision and control over the

ordering, distribution and administration of treatments and tests. The

remaining principal source of error which this Positive Patient

Identification - Step 5, will alleviate is the improper identification

of the patient for whom the treatment is intended by the unit personnel.

. This Positive Patient Identification is based upon a characteristic

array or pattern which is peculiar to a given patient and which can be

recognized by a simple device. This characteristic pattern will be

printed on the patient's wrist band and on all work orders and treatment

packages intended for that patient. Before administering a treatment

to a patient, the person doing the administration will compare the pat-

tern on the wrist band to the pattern on the work order by the use of

this pliers-sized device. The device makes a verification mark on the

work order if and only if the patterns correspond.

Step 6 - Input of Tabular Information-Phase I   Early 1964

The next logical step in the growth of a patient information control

system is the inclusion and analysis of additional information in the

system. The first such additional information will be the fairly simple

report type of data such as most clinical laboratory reports. The same

equipment used to collect this simple tabular data will also be used to

add speed and flexibility to some of the earlier functions. In particular,

the manual transcription and mechanical transmission stages at the

input end of the Doctor's Orders Processor - Step 1 - will be supplanted

by the automatic remote input units required for this step 6.

Step 7 - Physiological Recording of All Patients   Late 1964

A second stage in the expansion of the information to be included in

The patient information control system will be the collection of phys-

iological data from all of the patients in the hospital. The scope of

physiological measurements made on all patients in a hospital will al-

ways be less than the scope of such measurements made on critically

ill patients. The utility and value of such measurements to improved

medical care is, however, just as great.

Step 8 - Laboratory Instrument Recording   Mid 1965

A great deal of the information originating in the clinical labora-

tories is now being generated by automatic laboratory instruments.

This Laboratory Instrument Recording - Step 8, will take the infor-

mation directly from these instruments, relate it to the proper patient,

analyze it and include it as another element of patient information.

Laboratory Instrument Recording will find its greatest value when

applied to laboratories which do analyses for other hospitals and lab-

oratories in addition to their regular work. The requirement for high

speed reporting of results is of paramount importance in this outside

work.

Step 9 - Input of Tabular Information-Phase II   Mid 1965

In Step 6 some of the relatively simple elements of tabular data were

put into the patient information control system. Included in this second

phase of inputting of tabular data are the more complex elements such

as medical histories, results of physical examinations, and the many

other types of stereotyped patient information generated within a hospital.

<u>Step 10 - Input of Textual Reports</u>   <u>1966</u>

The final element of patient information included in this growth pattern of an electronic patient information control system is the written report. This will cover doctors' notes, nurses' notes, operation reports, anesthesia reports, labor progress records, case summaries, etc. The procedure in collecting this information will be to receive the reports, usually in verbal form but often in writing, and manually transcribe it into machine assimilable form. Eventually, it is expected that direct voice-to-machine data transmission may be possible but this requires a technological breakthrough which is probably some years away.

<u>Step 11 - Data Search and Retrieval Program</u>   <u>1966</u>

At the conclusion of Step 10 - Input of Textual Records, all of the information which is normally recorded about the patient is now stored in the necessary form for further processing and analysis. At various points during the process of collecting this "total" information package, use has been made of the information at hand to derive additional specific information about a patient and also some general information of value to the hospital and to the entire medical field. As the package of information becomes more "total" the derived information on

a given patient can become more specific and the general derived information can have wider and greater value. However, at the same time this "total" information package has become considerably harder to search, especially for the general purpose applications. Some systematic means of finding information must be utilized.

This next step, the Data Search and Retrieval Program, will provide such a systematic information finding fraction.

Step 12 - Electronic Record Storage   1967

At the conclusion of Step 10, all of the patient information which is required for analysis has been recorded in computer format, namely on magnetic tape. At this point two problems will appear which relate to the permanent storage of the patient information for medical record purposes. The first is that of storage space. It is estimated that the medical record files of a 400 bed hospital are likely to increase by about 1000 reels of magnetic tape per year. This is about the same volume of storage space as if the information had been recorded and stored on paper. Microfilm would be undesireable because of the need for machine searching the medical record files.

The second problem is storing those documents which are of a pictorial nature. These include such things as X-ray films, photographs, legal documents requiring signatures, etc. These cannot, of course, be recorded on magnetic tape and would have to be stored in their original form.

Step 12 - Electronic Record Storage will be able to solve both of these problems by the use of thermoplastic film recording. This is a newly developed recording process which can record both digital and pictorial information with extremely high storage density. The 1000 reels of magnetic tape per year would be reduced to about 5 reels of thermoplastic tape. This tape would be handled in essentially the same manner as the magnetic tape but it would be able to include all of the pictorial information as well. The tape could be reread and the pictorial data reproduced on request.

Step 13 - Patient Monitoring Computer   1967

In the original Alarm and Display Monitors - Steps 2 and 3, a certain amount of computing (rate and rhythm derivations, alarm level detection) was performed on a real time basis using analog computing equipment. Having gained the operational experience with these basic units it is possible, at the time recommended for Step 13, to permit the monitoring to become more flexible. This would encompass such improvements as multiple alarm levels (these might be Closer Supervision, Alert, Emergency), acceleration of recording cycles as a function of alarm conditions, more complex signal derivations (wave form analysis, P-R interval, respiratory phase relationships) and many others. Analog computing equipment would be unsuitable for this level of flexibility and complexity and digital computing equipment would be in order.

- 16 -

Step 13 - Patient Monitoring Computer will be an on-line digital computer programmed to perform all of the monitoring, alarming and computing elements required. Measuring, displaying and recording equipment installed in Steps 2 and 3 would remain unchanged.

The computer itself would be an entity, separate and distinct from the basic data processor. In order to improve reliability of performance of this critical function it will be possible to switch the computing to the central basic data processor in the event of any malfunction in the Patient Monitoring Computer. This would, of course, hold up all other less urgent work which would normally be performed by the central processor until the monitoring system was put back into operation.

Step 14 - Information Feedback Between Central   1968
           Processor and Patient Monitoring Computer

At about this time sufficient information will have been collected, correlated, analyzed, etc., to be able to form some relatively simple automatic links between the patient monitoring system and the central processor. For example, depending on the various types of patient conditions and treatments, different signals will be computed, alarm levels set, recording cycles programmed, etc.

In the opposite direction, alarm conditions detected by the monitoring computer may cause the central processor to generate certain treatment responses as preprogrammed by doctors' orders, or PRN's, or

hospital standing orders. Also, current condition information as de-
rived from the monitoring computer may be combined with earlier in-
formation stored in the central processor to generate more complex
alarms or other action signals.

Step 15 - Diagnostic Tool   1969

One of the major accomplishments in the approach to an ultimate
EPIC system is the step which provides a system which can provide
direct assistance to the doctor in his search for diagnostic information.
At about this period of time, the Diagnostic Tool - Step 15, can pro-
vide such direct assistance. Some of the assisting functions which
can be performed are as follows:

Testing Hypotheses. The doctor states the patient conditions required
for his hypothesis and the patient can quickly tell him whether or not
these conditions are present or whether it needs more information
about some condition.

Suggesting Possibilities. A little closer to the ultimate system and
requiring considerably more analysis is the ability to suggest to the
doctor the various possible diagnoses which are present.

Suggesting Additional Tests. Given the capability to suggest possible
diagnoses, it would require relatively little additional work to suggest
further tests to eliminate or confirm certain of the possibilities.

- 18 -

Calculating Probabilities. A significant step beyond the suggestion of possibilities is the establishment of probabilities of each suggestion based on general incidence and the particular condition present.

Part 3

FUNCTIONAL DESCRIPTION

FUNCTIONAL DESCRIPTION

Introduction

This section covers a description of the functions to be performed in Steps 1, 2, 3 and 4 of the Growth Pattern of an EPIC system as described in the previous section. These steps cover the Basic Information Processor, Doctors' Orders Processor, Alarm Monitors and Display Monitors.

Step 1 - Basic Information Processor

The principal function to be performed by an EPIC system is Information Control or Information Processing. While some of this Information Control is performed at remote locations, such as at the Alarm and Display Monitors, a large and rapidly increasing share of it will be performed at the central processing installation. The initial application on this Basic Processor will be Doctors' Orders Processing, but as the scope of the system expands, additional Information Control Functions, as outlined in the Growth Pattern, will be added to the work load of the Basic Processor.

The Basic Information Processor is built around a large scale general purpose digital computer, specifically the GE225, which has found such wide application in banking and in performing engineering calculations. The GE225 information processor has been particularly designed for installations with characteristics similar to the planned EPIC system; that is, it has been designed for a wide variety of input and output

equipment and it has been designed to be expandable without modification.

For example, the unit can accept input data from punched cards, punched paper tape, keyboards, printed magnetic characters and magnetic tapes. It can put information out in the form of punched cards, punched paper tape, high speed printed forms, typewriter pages and magnetic tapes. The standard memory of the device is high access speed magnetic cores to which can be added magnetic tape, random access magnetic discs, and additional magnetic cores.

The specific GE225 data processing system which will be used as the Basic Information Processor of the planned EPIC system will consist of a medium size memory central processor, magnetic tape units for additional memory, punched card input and output equipment and a high speed printer.

Doctors' Orders Processor

All of the medical care provided to patients in hospitals is the result of specific orders written for each patient by a doctor. The quality of medical care provided by a hospital is largely a function of the quality of these doctors' orders and the completeness and accuracy with which they are accomplished by the hospital staff.

The accomplishment of their orders is a team function carried out by the entire hospital staff, but the ultimate responsibility for ensuring

that these orders are carried out completely, accurately, on the proper patient, at the proper time, etc., belongs to the head nurse on each nursing unit. It is she who must check the original order as written by the doctor, request the necessary support, both material and functional, from the other departments of the hospital, supervise the accomplishment of these orders on the patient with delivery of the patient to the department performing this function, and finally check on and record the proper accomplishment of each and every order. The Doctors' Orders Processor, as planned in this EPIC system, will relieve the nurse of some of the more routine of these functions, it will provide her with close support in the performance of the others, and it will provide an added safety precaution on all of these functions.

The operation of the Doctors' Orders Processor is shown on the chart. The original order will be filled out by the doctor on a printed form. This will then be sent to the central processor by pneumatic tube. The addition of remote input stations in Step 6 will permit this information to be put directly into the system without the use of pneumatic tubes. At the central processor the original order is first compared with hospital standing orders and known patient condition to determine compatibility. Any discrepancies will be referred to the ordering physician for rechecking.

After this step the order will be put into the main portion of the system. The main output will be work orders for specific functions to be

COMPONENTS OF BASIC INFORMATION PROCESSOR

| CAT. NO.	DESCRIPTION
C225B	Central Processor, includes control panel, desk, monitor typewriter, 8000 word internal memory, completely solid state circuitry.
J225A	3-Way compare, address modification unit. (Internal accessory)
J225B	Automatic interrupt unit. (Internal accessory)
D225B	Card reader and control. (400 card per minute operating speed)
E225C	Card punch (100 card per minute operating speed)
E225B	Card punch controller.
T225A	Six magnetic tape handlers. Information transfer rate 15,000 characters per second.
U225A	Magnetic tape control.
P225A	Control and printer (900 twelve inch lines per minute operating speed).
24	Three keypunch.
548	Interpreter (card printer)
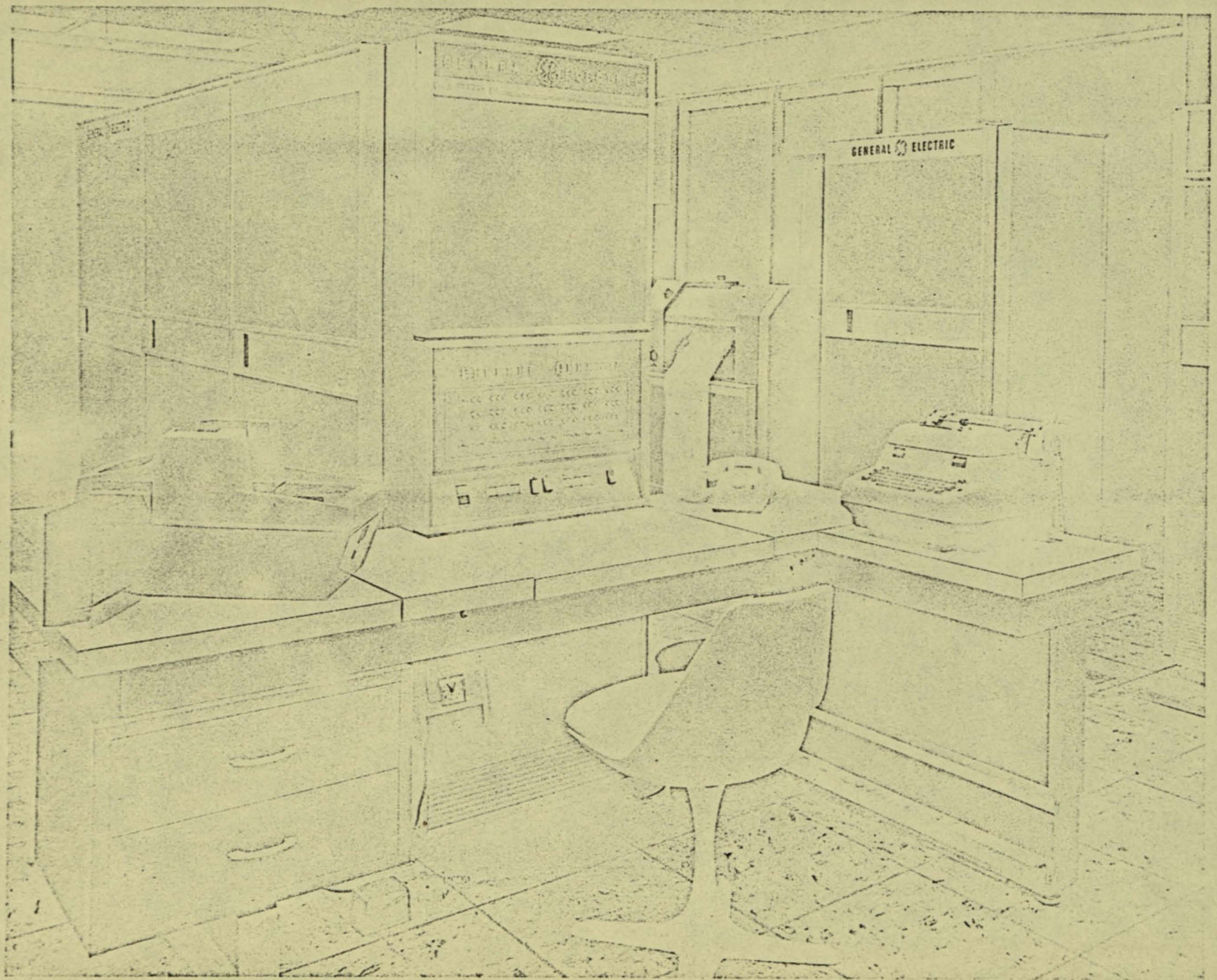
CENTRAL PROCESSOR
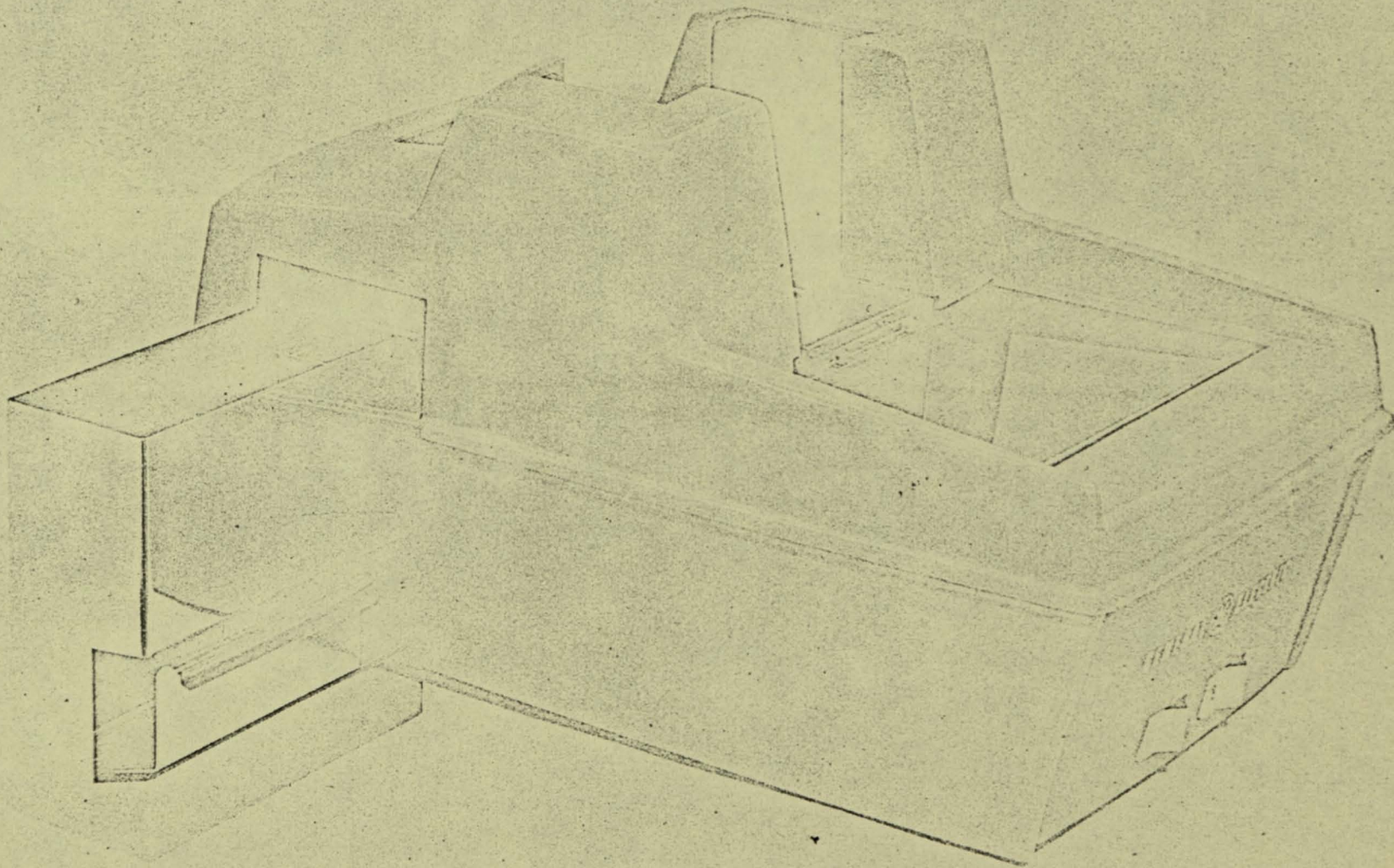
CARD READER
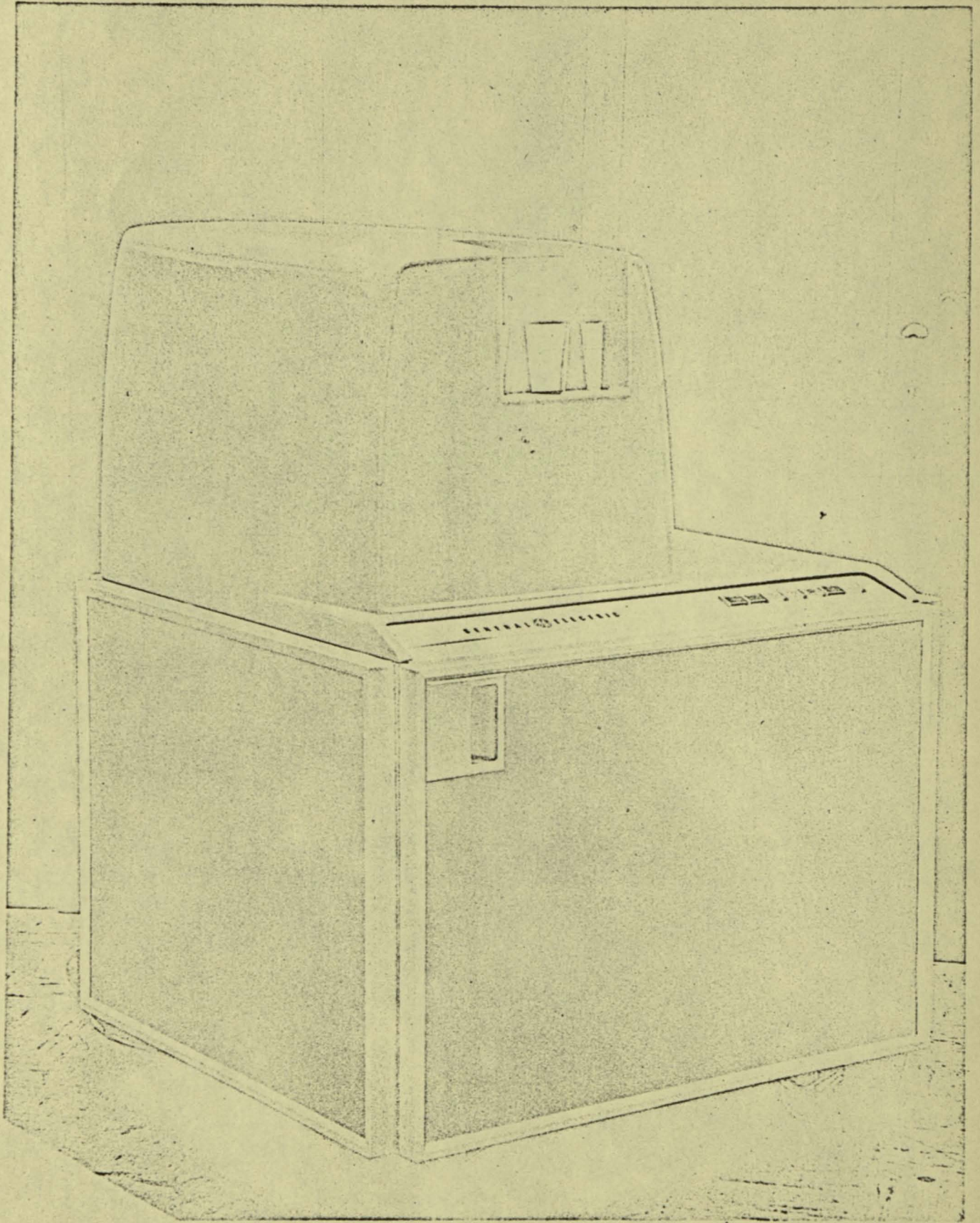
CARD PUNCH

MAGNETIC TAPE HANDLERS (6)
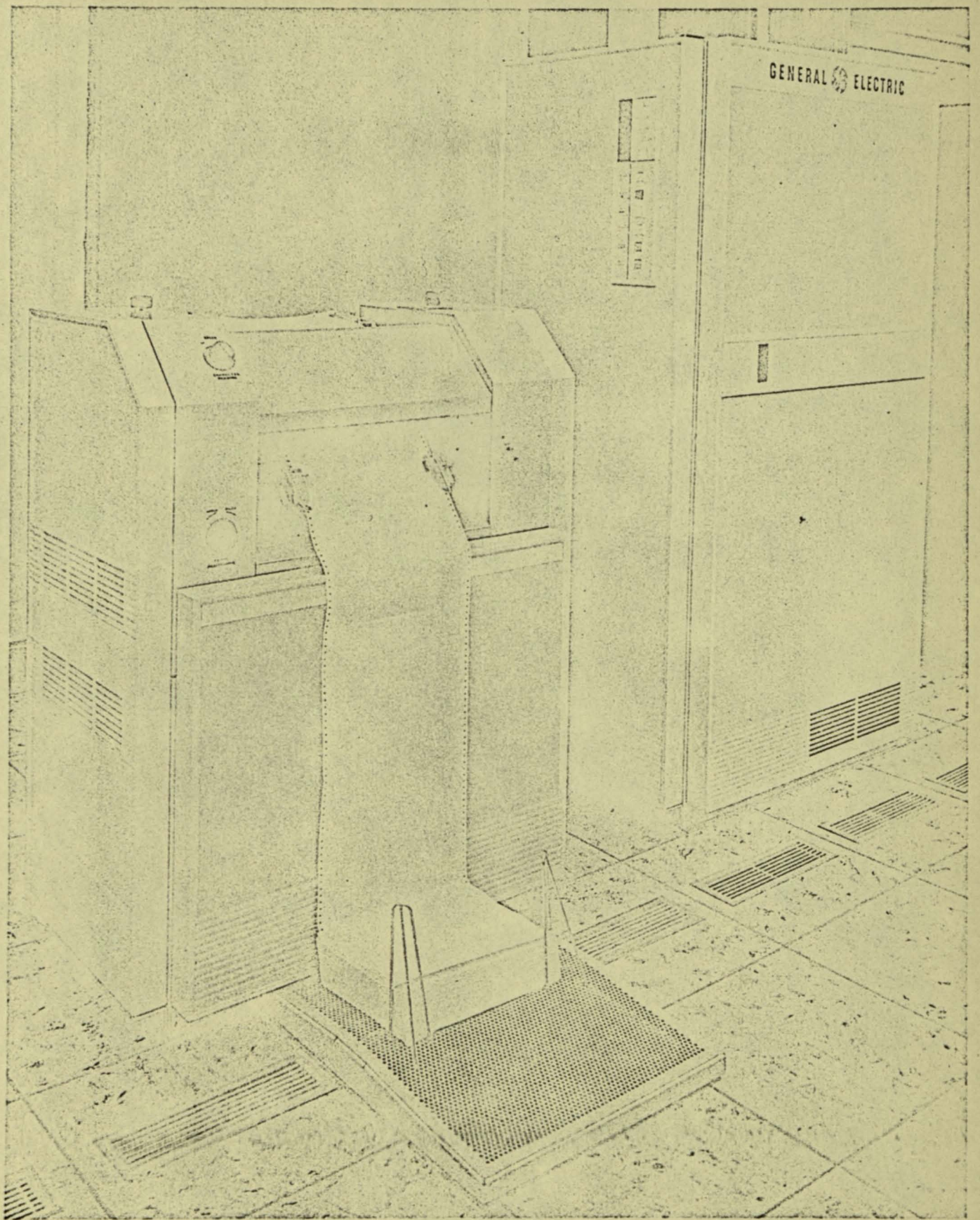
HIGH SPEED PRINTER

carried out on a specific patient at a specific time. The processor will prepare these orders, send them to the proper action location (nursing station, pharmacy, diet kitchen, laboratory, etc.) shortly before the action is required. Upon completion of the required action the work order will be marked as being accomplished and returned to the central processor. Reports will be prepared periodically listing work accomplished and remaining to be accomplished.

In addition to the work orders, other reports, listings and schedules will be prepared, such as daily work schedules, appointment schedules, patient treatment summaries, etc. Also, on receipt of each report of a treatment or test completed, that fact can be released to the billing and other business functions for pricing, billing, insurance breakdowns, inventory control, etc.

Step 2 - Alarm Monitors

The primary purpose of the system is to activate annuncitors which alert nursing personnel so that immediate and specific corrective care can be given the "alarmed" patient. In addition, displays and records are generated by the equipments to aid the doctor in his diagnosis and provide data for patients' records and medical research studies.

Three types of equipment for three areas of the hospital will be fitted with this equipment. They are a large unit (17 to 25 beds) for intensive case-recovery rooms, a medium sized unit (8 beds) for use on a portion of an otherwise standard nursing unit, and a single bed mobile unit for

use in the obstetrical suite or in any bed in the hospital.

A number of sensors (8 in the large and medium units and 6 in the portable unit) can be attached to the patients. The signals from these sensors are amplified to a standard level for system use. Additional observations are performed on some of these signals resulting in derived functions such as rates, rhythms, volumes and peak magnitudes. These sensors plus derived signals total 13 functions per patient for the large and medium units, and 11 functions for the single bed mobile unit.

All of these functions are carried by separate wires to the required points of the system. All of these lines (functions) are alarmed by individual circuitry which includes an annunciator light, key operated high and low alarm setting dials, and key operated alarm reset.

An automatic typewriter alarm recorder will provide a typed copy of the event, including time and identification of the alarm and its reset. The nurse will be required to manually enter her identification and corrective action taken. An edge punch card reader may be used for this purpose.

For the large and medium sized units, an additional record associated with the alarm events is that produced by the "fast" analog recorder (oscillograph). An alarm associated with either EKG or respiration will initiate a short period of recording of the EKG or respiration wave shape. By the optional addition of a temporary signal delay
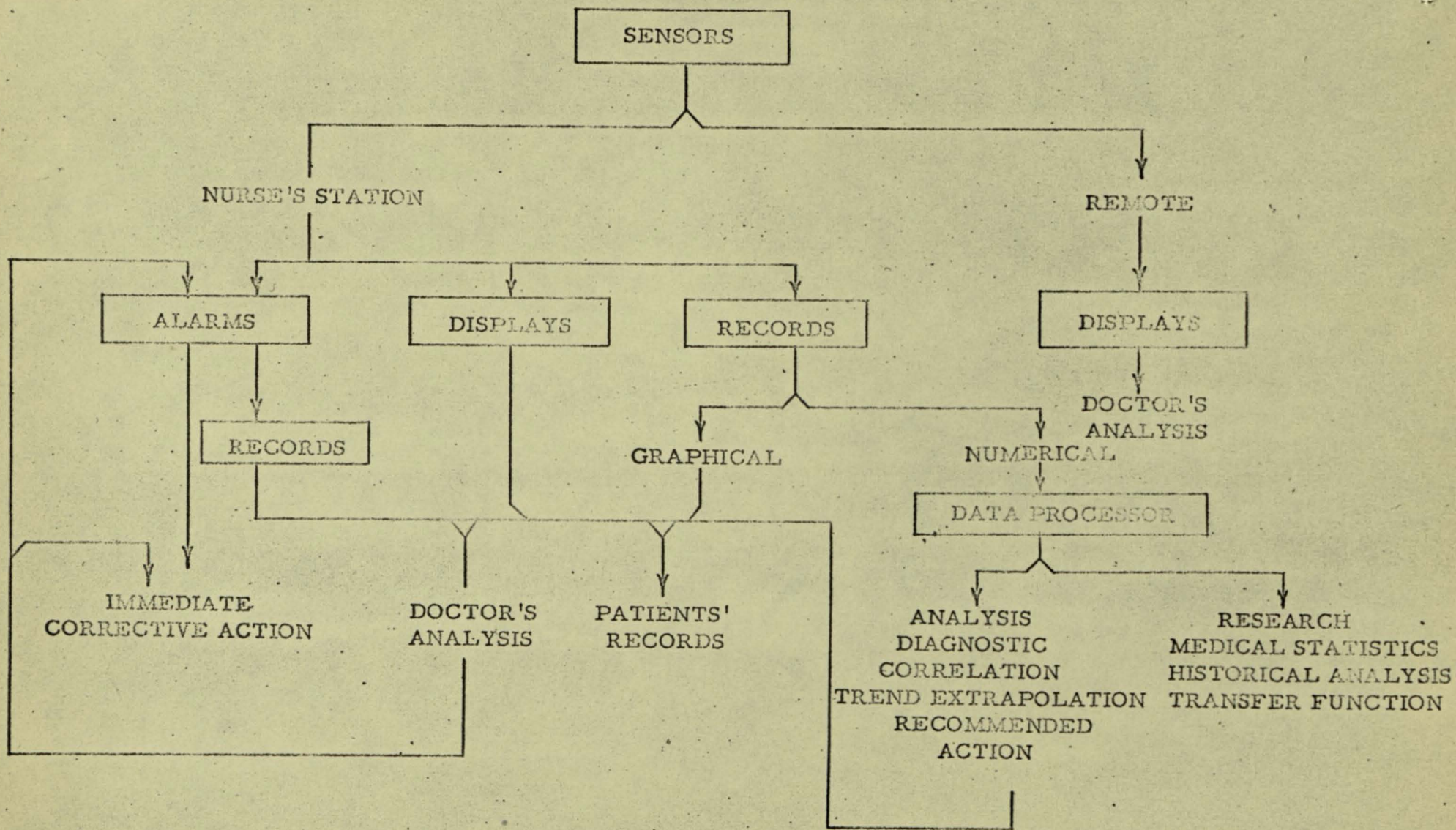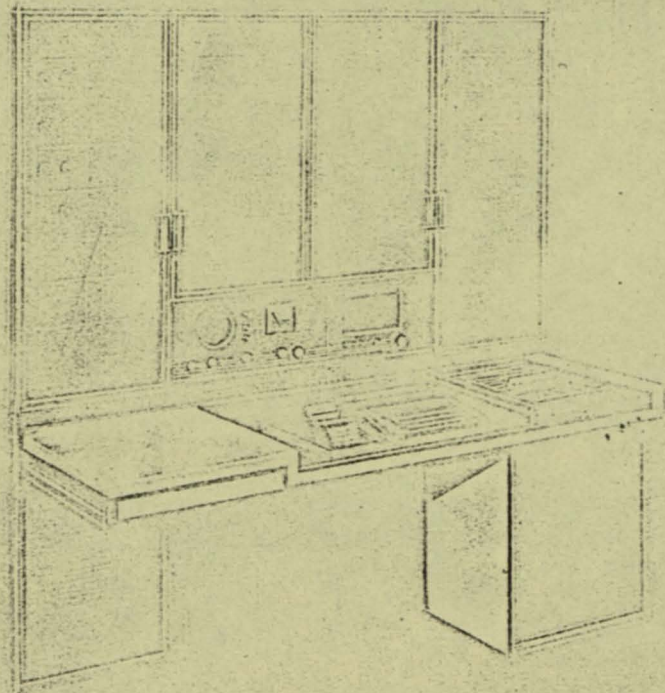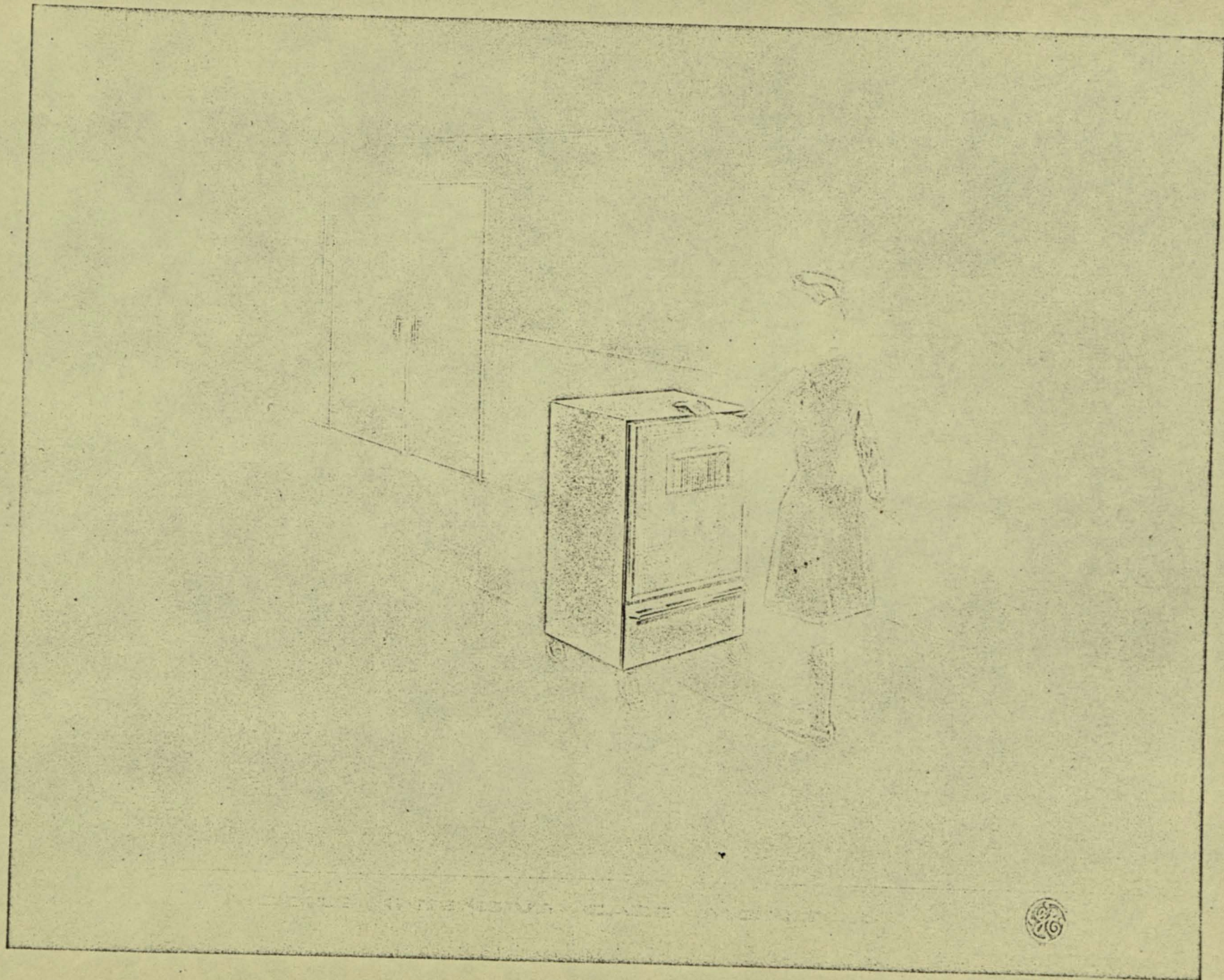
ALARM MONITORING FUNCTIONS

unit, the signal for a short period previous to the alarm can also be recorded. Such a "fast" analog recording will be useful in determining the cause of the alarm.

All of the functions may also be graphically recorded. The data sampled and rate of sampling would be selected by the nurse per doctor's instructions. A given chart could be removed and examined by the doctor to determine patient condition trends for the previous eight hours without interrupting the plotting of the other patient charts. These charts would later be filed in the patient's file.

The same functions which are graphically recorded in the large and medium sized units will also be digitized and numerically recorded on tape, along with patient and function code information. This data is thus available for analysis by the computer and current feedback to the doctor for better patient care. Also, it serves as a readily searchable data storage for medical research studies, etc. This will be described in more detail in Step 4 of this study.

The large and medium sized units have displays available on their respective central consoles and on a portable unit. The large unit has displays also in a doctor's anteroom. A selector switch for each display device will connect it to the desired function. Oscilloscopes and meters are at all locations. Respiration sound speakers are at central console and doctor's anteroom. The doctor's anteroom is also equipped with an oscillograph.
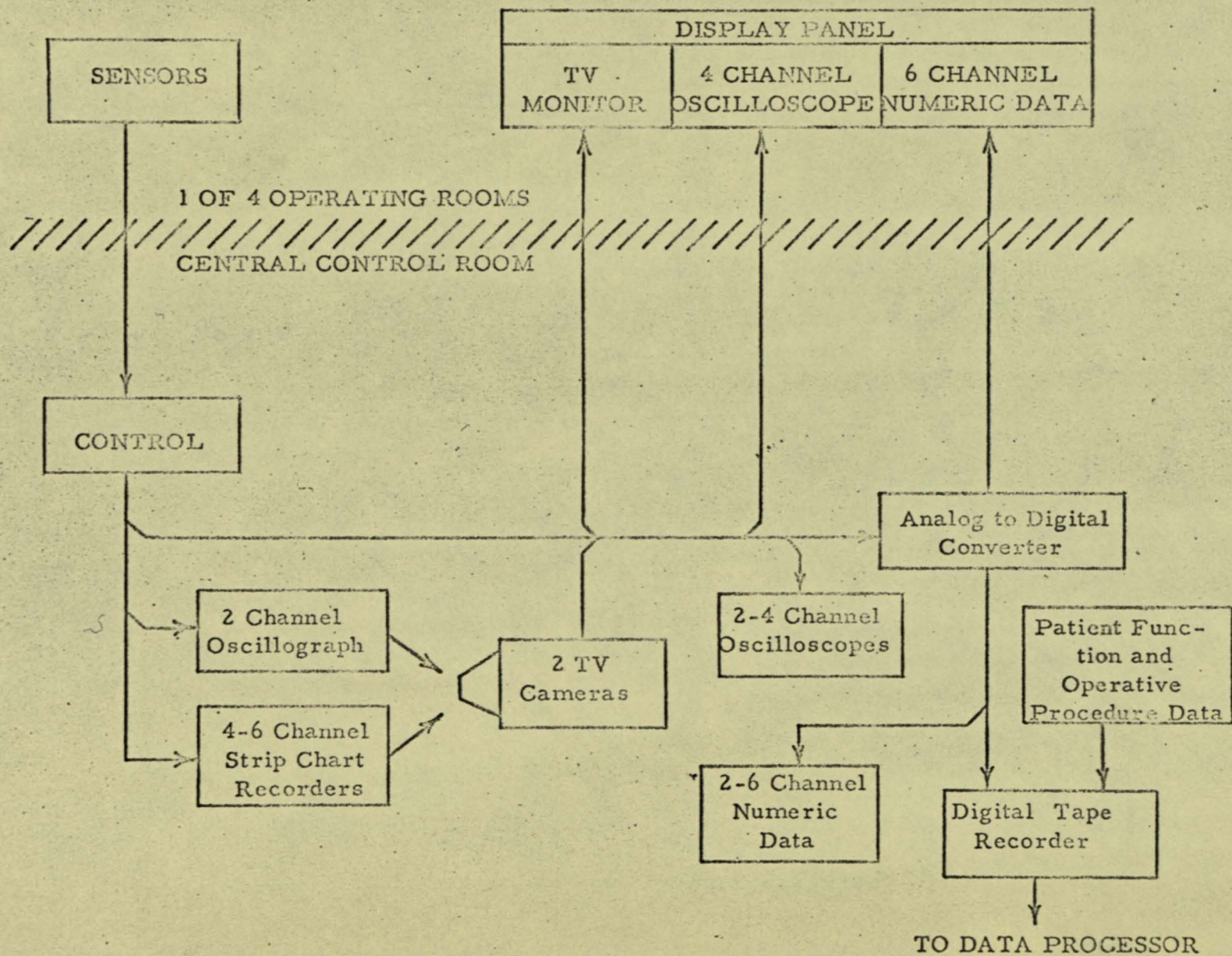
Step 3 - Display Monitors

The function of this equipment is to provide data on the condition of the patient to the operating team. This is accomplished by a system of sensors attached to the patient and by an organized display panel. As such its intended usage is in a four room operating complex serviced by a single central control room and also in a single operating room or delivery room. Additional outputs of the equipment include "fast" and "slow" graphical records for subsequent study and for the patient's record and numerical records suitable as input information into the data processor. There are no alarm functions associated with this equipment.

In order to keep the operating room as uncluttered as possible, only sensors and "clean" displays are located within the operating room. An overhead crane will be used to locate the equipment in the desired position (including height). The displays will consist of (1) a 4 channel oscilloscope, (2) six 3 digit numerical display channels and (3) a TV monitor for repeating information from the oscillographs and strip chart recorder at the central console. There is one portable TV monitor (large screen) that can be ceiling mounted in any operating room to provide extra display capabilities.
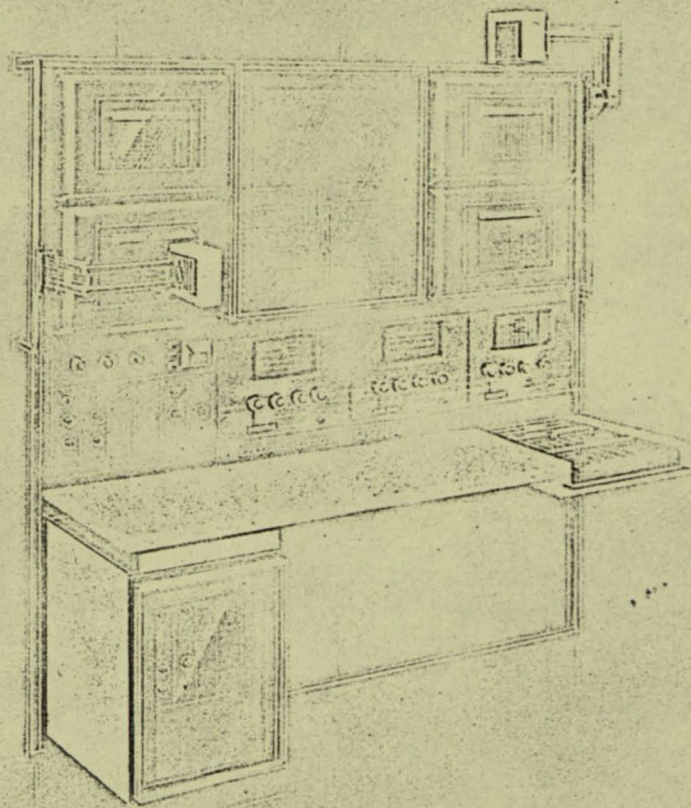
The design intention is to locate all equipment not directly concerned with patient sensors and display at the central control console. This reduces the bulk in the operating room for cleanliness and safety, places

DISPLAY PANEL

TV MONITOR	4 CHANNEL OSCILLOSCOPE	6 CHANNEL NUMERIC DATA

SENSORS

1 OF 4 OPERATING ROOMS

CENTRAL CONTROL ROOM

CONTROL

Analog to Digital Converter

2 Channel Oscillograph

2 TV Cameras

2-4 Channel Oscilloscopes

Patient Function and Operative Procedure Data

4-6 Channel Strip Chart Recorders

2-6 Channel Numeric Data

Digital Tape Recorder

TO DATA PROCESSOR

DISPLAY   MONITORING   FUNCTION
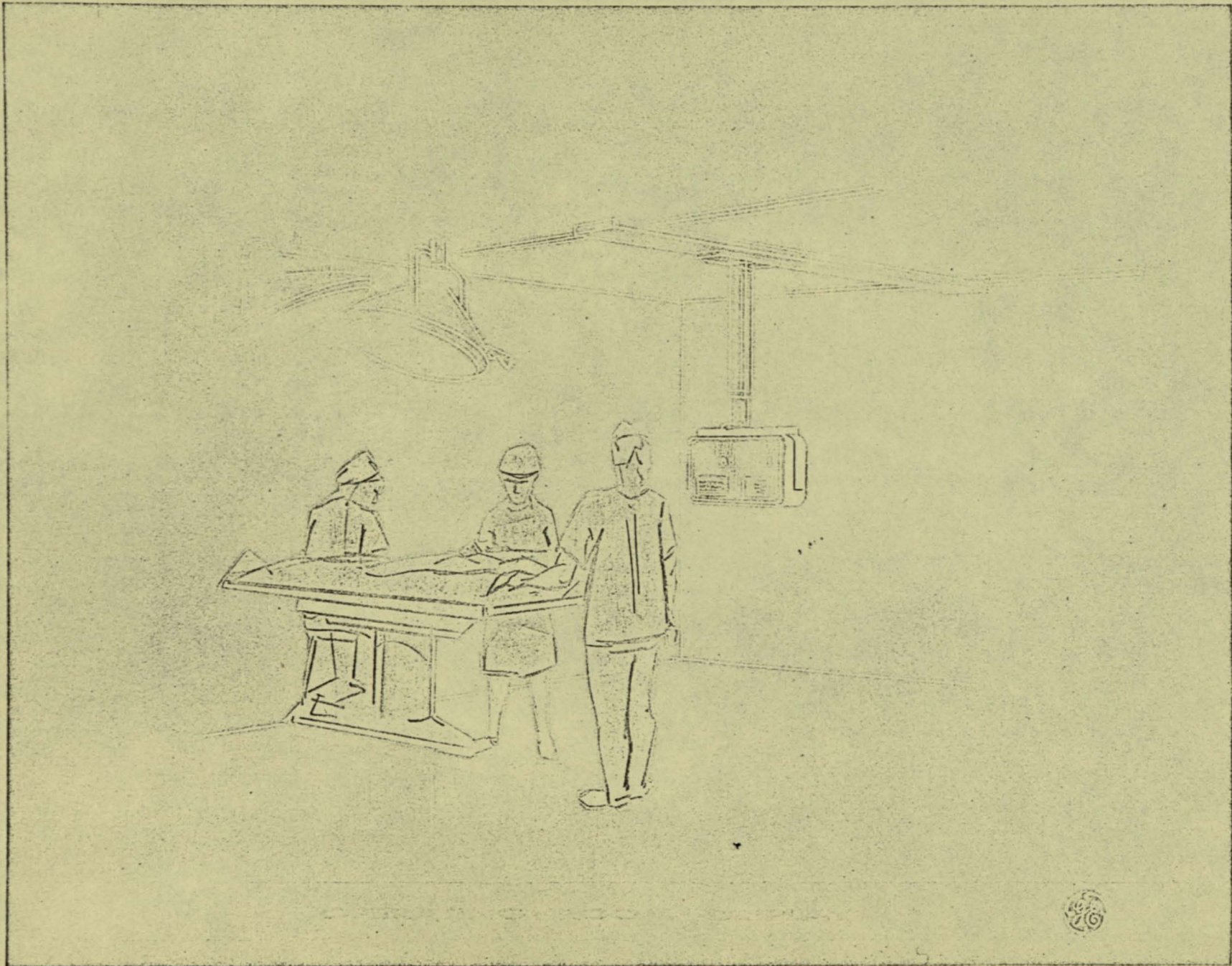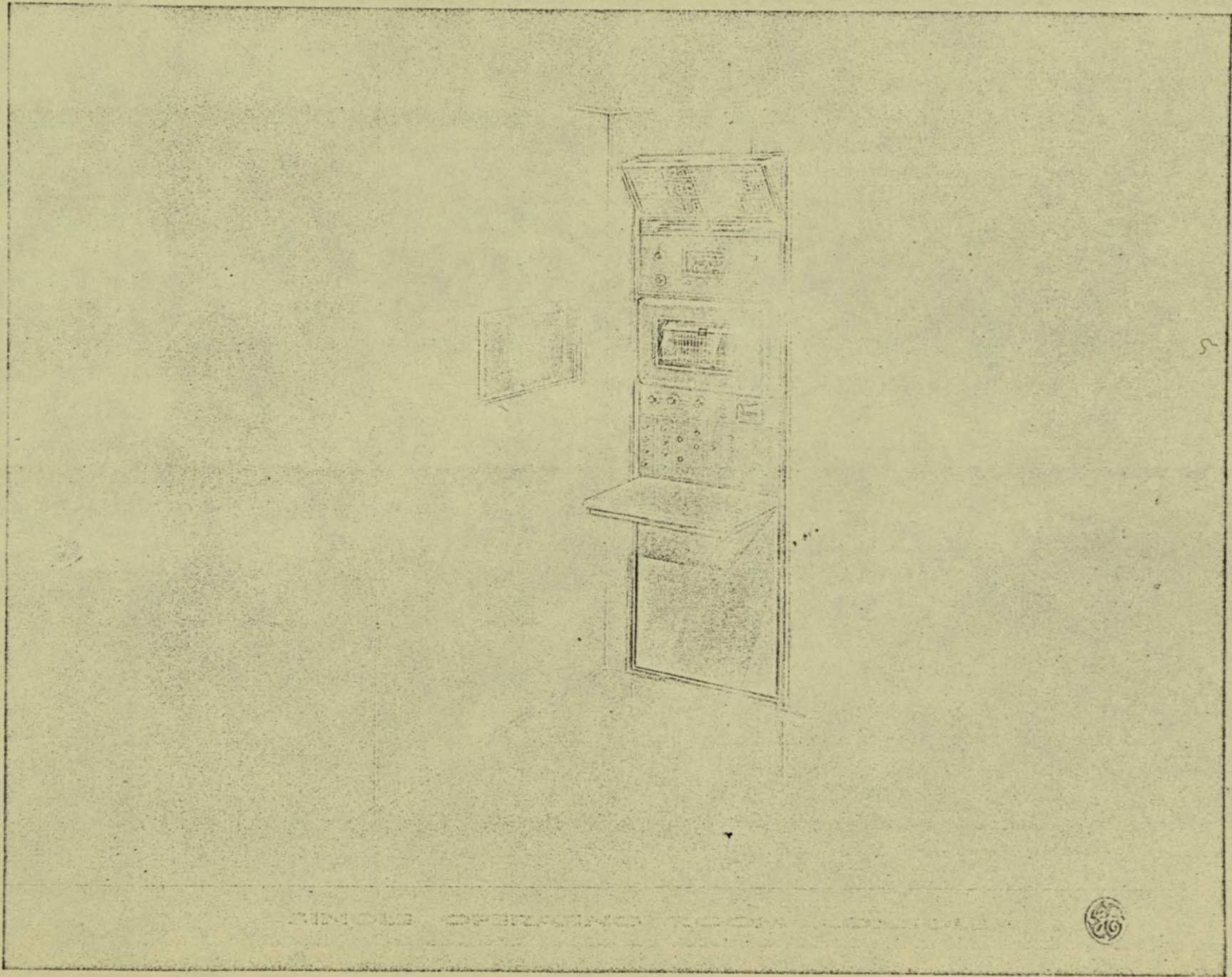
MULTIPLE OPERATING ROOM CONTROL

equipment that requires servicing (paper loading, adjustment, initial function setup, etc.) outside the operating room, and is more economical of personnel and equipment. Use of closed circuit TV make this practical.

The records produced by the strip chart recorders and oscillographs will be available for future analysis and patients' records files. Also, all the information presented on the numerical display panels are digitally recorded on tape along with patient, function and operative procedure information. This digital tape file will serve as an input source to the data processor. This operation is described in Step 4 of this study.

The single operating room equipment is functionally the same as that for the multiple operating room complex. Since it is designed for only one room, the use of closed circuit TV techniques are not as attractive and are not used. Instead, the console will be located adjacent to the operating room so that records can be viewed through a window.

Step 4 - Digital Recording of Physiological Measurements

As noted previously, information which has been utilized in the monitoring systems will also be collected and recorded in a form in which it could be searched, reorganized and analyzed by the information processor. The equipment used to implement this step consists of collectors, analog-to-digital converters, and digital recorders. Much of

this equipment will be included in the central monitoring consoles and it will thus be desirable to install this equipment with the original console.

The information thus recorded will go to the central processor which will perform some preliminary reorganization to collect this information by patient, by function and by time of measurement. At this point the information is ready for detailed study and analysis by the medical staff.

There is an infinite variety of uses to which the hospital may put this information. Some of the classifications of these uses are as follows:

Field of Application. Some of the analyzed information may relate directly back to the patient, such as response to treatment. Some may relate to the clinical operations of the hospital, such as the number of cases of fibrillation alarms following certain treatments. Some may have general application to general medical science in controlled experiments, such as the response of patients with and without certain treatments.

Scope of Analysis. Occasionally the information may involve only a single variable. For example, trends in heart arrhythmia over a period of time. More often, the information will relate two or more variables such as the response to a particular treatment as a function of time, or the correlation of one variable as a function of another. A third type of analysis will be a multiple

correlation of variables to probe causes and effects.

Purpose of Analysis. In many cases the analysis will simply be to test hypotheses or to look at some difficult information from another dimension. In other cases the analysis will be more specific, such as the establishment of standards for the operation of the equipment itself, for the use of other treatments or equipment, or for comparison with future tests planned on the patient himself. Another purpose will be to test specific new drugs or treatments, or equipment in controlled tests.

Part 4

SYSTEM DESCRIPTION

SYSTEM DESCRIPTION

The foregoing sections have described in general terms the Growth

Pattern of an EPIC system and have given a functional description of

Steps 1, 2, 3 and 4 in this Growth Pattern. This section will describe

in more specific terms the equipment procedures necessary to imple-

ment Steps 1, 2, 3 and 4 of an EPIC system.

Step 1 - Basic Data Processor and Doctors' Orders Processor

In the following paragraphs Step 1 of a Patient Information Control system is broken down into functional subsystems. These are not separately performed operations but form a continuous equipment run.

Input Processing Subsystem (A)

Printed forms for Doctors' Orders, admissions office, etc., would be designed to facilitate keypunching. Adjacent to each description would be code numbers and blank spaces for indicating check marks, quantity, time or other notation. To minimize card preparation, only the codes and written data would be punched. There would be no effort to segregate the various types of input data in the GE225 system. In fact, certain of the input cards would be those previously produced by the computer. (These were the cards sent to execute a Doctor's order, returned with verification or explanatory information written thereon for punching and re-entry into the computer.)

With a batch of cards in the Card Reader and Central Processor Switches set to execute the Input Processing Subsystem Program, the equipment would be started and perform the following operations automatically:

The computer would bring in card contents, would edit the input, compare against hospital regulations, extract data from the computer master file, do necessary comparisons and store the transaction at the end of the other entries on a magnetic tape.

Any discrepancy during comparisons would cause a typeout of the input entry with explanatory note for transmission to the originator for his reconsideration.

For visual verification purposes, the high speed printer would produce a full readable printout of the input card contents and not just a duplication of codes.

Cards needed for laboratories, kitchen, pharmacy, etc., to execute a Doctor's order within the "current time period" (2 hours or as defined) would be automatically punched. Orders that are to be repeated in future time periods would be stored on a magnetic tape for later use. (See Subsystem B.)

Card punching would be translated into readable card printing by the #548 Interpreter before transmission to the "Action" station. High-speed printer listings would be used to sight verify against original forms.

Periodic Order Schedules Subsystem (B)
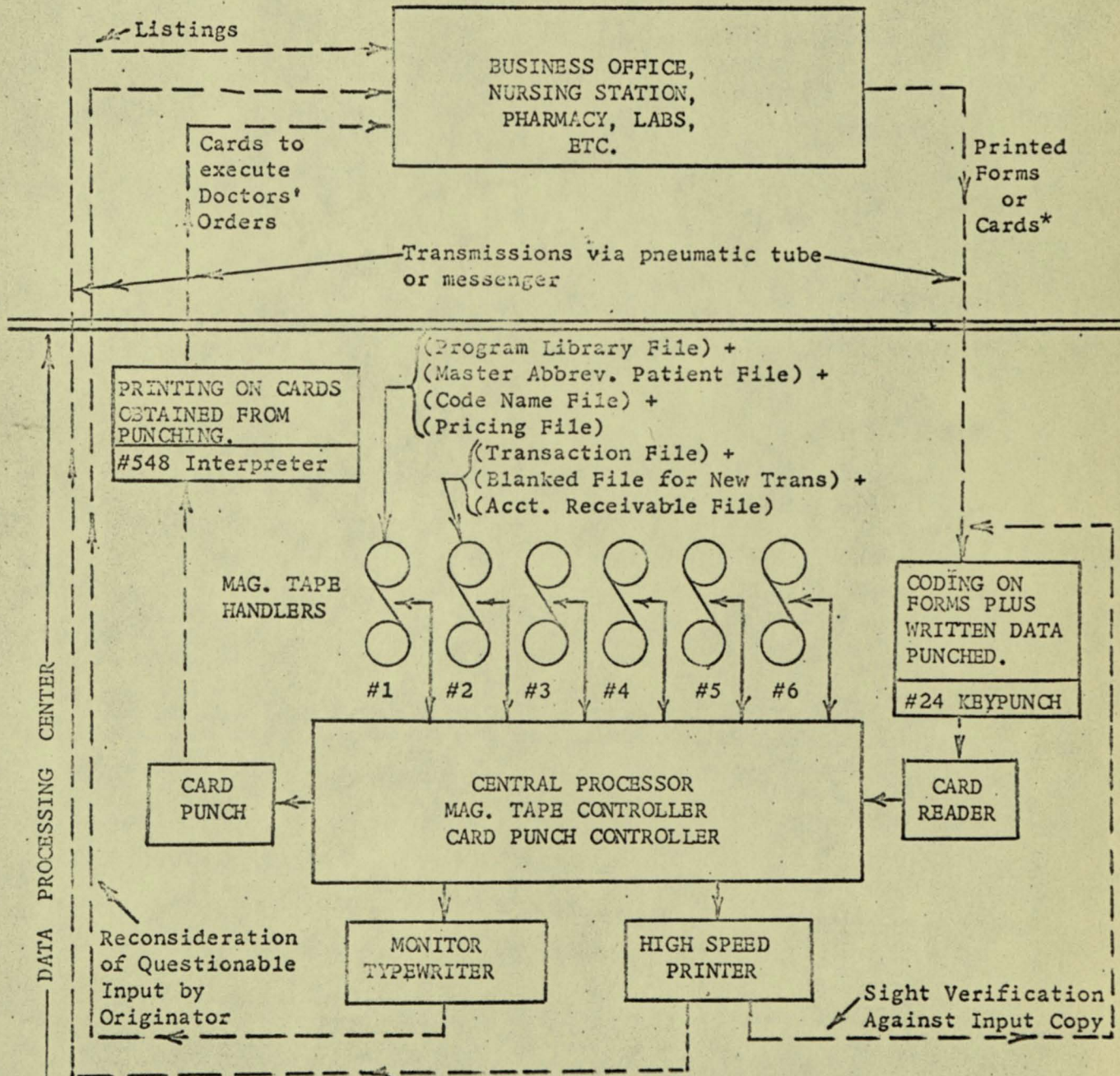
At a specified time prior to each "standard time period" transaction contents on magnetic tape would be processed through the computer and those entries scheduled for the desired time period would be automatically arranged as described below.

Records would be arranged chronologically for each nursing center and a printout of the data would be produced. (This would give each

INFORMATION PROCESSOR

OVERALL SYSTEM
SCHEMATIC FLOW CHART

Listings

```
BUSINESS OFFICE,
NURSING STATION,
PHARMACY, LABS,
ETC.
```

Cards to
execute
Doctors'
Orders

Printed
Forms
or
Cards*

Transmissions via pneumatic tube
or messenger

```
PRINTING ON CARDS
OBTAINED FROM
PUNCHING.
#548 Interpreter
```

(Program Library File) +
(Master Abbrev. Patient File) +
(Code Name File) +
(Pricing File)
(Transaction File) +
(Blanked File for New Trans) +
(Acct. Receivable File)

MAG. TAPE
HANDLERS

#1 #2 #3 #4 #5 #6

```
CODING ON
FORMS PLUS
WRITTEN DATA
PUNCHED.
#24 KEYPUNCH
```

```
CARD
PUNCH
```

```
CENTRAL PROCESSOR
MAG. TAPE CONTROLLER
CARD PUNCH CONTROLLER
```

```
CARD
READER
```

DATA PROCESSING CENTER

Reconsideration
of Questionable
Input by
Originator

```
MONITOR
TYPEWRITER
```

```
HIGH SPEED
PRINTER
```

Sight Verification
Against Input Copy

* Certain cards previously punched by GE225 for a
Doctors' order may again be processed through
after punching verification or explanatory data.

nursing center a listing of the prescribed orders for their patients.)

Records would then be rearranged by "action" addresses (such as "Central Pharmacy", "Diet #3", etc.) and secondarily arranged chronologically and by type of service. A listing for each "action" address would be produced and a total for each "type of service" generated at the bottom.

In addition, punched cards would be produced for each "action" addressee to be used as the official working document and would accompany medicines, diet, etc., and as desired have blank spaces to record nurses or action addressee's verification of actual accomplishment or reason for nonaccomplishment. Such returned cards and not the original order would be the basis for billing.

Patient Log Subsystem (C)

Processing of this subsystem would be scheduled for early morning, such as for 5 AM. The transaction file on magnetic tape would be automatically arranged into chronological order by patient number. It would be printed out to give a log of the previous 24 hours and the prescribed events for the coming 24 hours. The printouts for each patient would be distributed to the nursing stations.

A "historical" tape file would be mounted and the elapsed entries would be transferred to it with the program deleting data deemed non-essential. The prescribed future entries would be retained for use.

- 37 -

Accounts Receivable (D)

Periodically financial transactions on the transactions tape are auto-matically posted to the Accounts Receivable tape and desired printouts obtained on a schedule on short notice basis.

Payroll Subsystem (E)

and

Inventory Control, Purchase Order, Accounts Payable Subsystem (F)

At specific times during the night, these subsystems would be run using patient transactions and master data stored in tape.

Other Projects ( )

Other programs should be developed by Hospital Data Processing personnel after operational date of January 1, 1963.

Step 2 - Alarm Monitors

The following chart summarizes the planned equipment placement for the alarm monitoring system.

Standard sensors are those which are built in and permanently assigned to the various system signal channels. The special sensors are select-able by plugging the desired sensor and associated amplifier into any of the available "special" system channels. Derived functions are those obtained by analog computation on the basic function. This will involve operations such as long and short term integration, ratio taking, peak level detecting, voltage clamping, etc.

ALARM MONITORING
(SUMMARY CHART)

	FUNCTION		ALARMED FUNCTIONS			RECORDED A. Fast Analog B. Slow Analog C. Digital D. Alarm			DISPLAYED Each device has a function selector switch associated with it.		
	Direct Sensor Functions	Derived Functions	17 Bed	8 Bed	1 Bed	17 Bed	8 Bed	1 Bed	17 Bed	8 Bed	1 Bed
STANDARD											
1. EKG (Wave Shape)	X					A	A	A ↑			
2. Heart Rate		X	X	X	X	BCD	BCD				
3. Heart Rhythm		X	X	X	X	BCD	BCD				
4. R-Wave Strength		X	X	X	X	BCD	BCD				
5. Respir. (Wave Shape)	X					A	A	A			
6. Respir. (Rate)		X	X	X	X	BCD	BCD				
7. Respir. (Rhythm)		X	X	X	X	BCD	BCD				
8. Respir. (Volume)		X	X	X	X	BCD	BCD				
9. Temperature	X		X	X	X	BCD	BCD				
10. Systolic Blood Pressure	X		X	X	X	BCD	BCD				
11. Diastolic Blood Pressure	X		X	X	X	BCD	BCD				
12. Labor Contractions	X				X						
13. Respir. Sound	X										
OPTIONAL											
14. Hemorrhage	X										
15. Blood Oxygen	X										
16. Peripheral Circ.	X										
17. Drip Flow	X		Any 4	Any 4	Any 1	BCD-Any 3	BCD-Any 3	B - Any 1			
18. Patient Motion	X							B - Any 6 except EKG & respir. wave shape			
19. pH	X										
Etc.											
Functions/Bed			13	13	11						
Functions/Ward			221	104	11						

DISPLAYED column annotations:

17 Bed: Central console-oscilloscope, meter & speaker — Doctor's anteroom-oscilloscope, oscillograph, meter & speaker — Portable unit – oscilloscope & meter

8 Bed: Central console – oscilloscope, meter & speaker — Portable unit – oscilloscope & meter

1 Bed: No Displays for Single Bed Unit Except those Associated with Recorded Data

1 Bed (RECORDED) note: B - Any 6 except EKG & respir. wave shape

- 39 -

The blood pressure sensor will be a mechanized arm cuff. The operation of this cuff will be automatic, and the programmed inflation and deflation cycle will be initiated at the desired intervals by feedback control from the central console.

Connection of the sensors to the patient will be made by a single cable harness that branches out to the various sensors. The harness will contain electrical and pneumatic power lines as well as signal lines. Sensor amplifiers are located in a wall unit at the head of the bed. Each sensor signal (2 to 10 volts) is transmitted by a separate wire to the central console.

For the 17 bed (expandable to 25) unit there will be a total of:

25 beds x 13 functions/bed = 325

individual alarm subpanels on the central console. Front mounted items on these panels will consist of an alarm annunciator light; concentric high and low alarm level set potentiometers with knobs calibrated in terms of the function, i.e., mmHg; and a three position toggle switch used to select the desired "slow" analog and digital recorder sampling rates of none, 5 or 30 minutes per sample. In addition to the alarm and switching circuits, the computational and clamping circuit's need for the derived functions are located in the chassis immediately behind the subpanel. These various alarm chassis will be pluggable and arranged in groups of 13 per bed. A key operated glass door will be hinged in front of these panels as a guard against tampering. The 8 bed intensive

care unit will be functionally identical with the exception that:

$$8 \text{ bed} \times 13 \text{ function/bed} = 104$$

alarm subpanels will be included. For the single bed or obstetrical ward unit there will be provisions for 11 alarm subpanels. In addition, there will be a single common alarm light located outside the door of the obstetric ward.

The "slow" analog recorders for the 17 and 8 bed unit will consist of built in X-Y recorders with coded type (per function) for plotting the functions versus time on a separate 8-1/2 x 11 inch sheets for each patient. Special graph paper, calibrated in time (0 to 8 hours), versus the various parameters, i.e., mmHg, will be used. Previous to loading into the recorder, the patient identification information and date will be entered on to the paper. These curve sheets will be manually loaded into their proper "trays". Automatic translation of these trays will bring the desired curve sheet into register with the X-Y plotter and a schedule is defined by the setup of the none, 5 or 30 minute sampling switches on the respective alarm subpanels. The point plotting rate is such as to enable complete recording of every alarmed function in the ward on a 5 minute schedule. The trays will be stacked in such a manner as to be easily accessible to the doctor. Examination of any chart will not interfere with the recording on the others. Twenty-five chart trays will be incorporated into the 17 bed unit for the anticipated expansion to 25 beds.

The single bed, or obstetric ward, "slow" recorder will consist of a 6 channel multipoint strip chart recorder. Recording will be on a 5 second per point cycle.

All information that is plotted in the 17 and 8 bed unit "slow" recorder is also numerically recorded. Shaft position digital encoders will be attached to X-Y plotters to provide the numeric function data. A digital clock will supply date and time, and coded patient and function information will be available from a paper tape reader and plug board respectively. A paper tape punch is used to digitally record this data for subsequent handling by the data processor.

A 4 channel oscillograph will be used for the 17 bed unit "fast" record. The 8 and 1 bed unit will each use a 2 channel oscillograph.

The oscillograph referred to in the summary chart for display in the 17 bed unit doctor's anetroom is a 2 channel instrument.

Step 3 - Display Monitors

The sensing components used in this equipment are the same as those used in the above described Alarm Monitors. The 11 standard functions related to EKG, respiration, temperature and blood pressure plus two spare channels for handling the optional function are included. Signals from the sensors will be processed at the central control console for display in the operating rooms. The equipment distribution is as follows:

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Single Operating Room

The equipment needed for the single operating room display monitor is much less than since only one room is required. In the single operating room the equipment is the same as that of the multiple operating room complex except no TV equipment is required. The control console will be located adjacent to and with window viewing from the operating room of the single 6 channel strip chart recorder and 2 channel oscillograph. Only a single 4 channel oscillograph and one 6 channel numerical display will be required.

Step 4 - Digital Recording of Physiological Measurements

Most of the equipment required to perform Step 4 will have been installed into the control consoles in Steps 2 and 3. This is necessary in order not to interrupt the performance of the Alarm Monitoring and Display Monitoring functions to install this additional equipment. Step 4 will complete the installation of the equipment and start the performance of the function.

As noted previously, the equipment consists of:

1. Information collection equipment or multiplexers.

2. Information identification equipment or encoders.

3. Analog-to-digital converters.

4. Digital data recorders.

Information will be gathered from all of the monitoring systems except the mobile Alarm Monitor which is excluded by reason of size. Each recording system will be self contained within each monitor console.