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Location of, and Distances Moved by, a Weaver in a Loom-Shed

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An analysis is carried out for the location of a weaver who controls a group of looms in a given layout so that he moves a minimum distance. The analysis is done by using a minimum approach for different types of movement. An example of the use of this analysis is given.

In a loom-shed, looms are usually installed in several rows and columns leaving room for passage as shown in Fig. 1. A weaver controls a group of looms ranging from 4 to 48, or more. The aim of the study is to determine the actual position of the weaver so that he can control all the looms efficiently, moving minimum distances in a most suitable layout. The study also determines the minimum distances moved and the time taken for his movement.

Location of Weaver

There are two methods to find out the location of the weaver amidst the looms so that he can control all the looms from that position. In solving this problem, one must know the distances from one loom to another and distances of passages from the looms, which give a distance matrix. The distance matrix is shown in Table 1 and the layout of looms in Fig. 2.

First method—The location of the weaver controlling a group of looms with an equal number of rows and columns or a single row or column is the centre of the rectangle formed by the looms. In Fig. 1, if a weaver controls section A or B, he can be stationed at the centre, but for section C the location has to be determined geometrically.

Consider one edge A of hexagon ABCDEF in Fig. 3 with coordinates (0, 0). Then O, the centre of the rectangle ABB′F, has coordinates $\left(\frac{b}{2}, h/4\right)$. Similarly, the coordinates for L, the centre of the rectangle EB′CD, will be $(3b/4, 3h/4)$. Hence M, the centre of gravity of the hexagon lying on the line OL, has coordinates (X, Y)

$$X=\frac{2b/2+3b/4}{3}=\frac{7b}{12};\ Y=\frac{2h/4+3h/4}{3}=\frac{5h}{12}$$

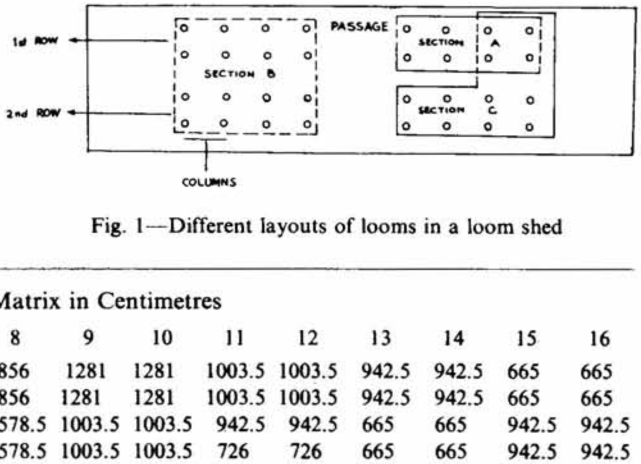


Fig. 1—Different layouts of looms in a loom shed

Table 1—Distance Matrix in Centimetres

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	55	277.5	277.5	578.5	578.5	856	856	1281	1281	1003.5	1003.5	942.5	942.5	665	665
2	55	0	277.5	277.5	578.5	578.5	856	856	1281	1281	1003.5	1003.5	942.5	942.5	665	665
3	277.5	277.5	0	55.0	301	301	578.5	578.5	1003.5	1003.5	942.5	942.5	665	665	942.5	942.5
4	277.5	277.5	55.0	0	301	301	578.5	578.5	1003.5	1003.5	726	726	665	665	942.5	942.5
5	578.5	578.5	301	301	0	55.0	277.5	277.5	942.5	942.5	665	665	726	726	1003.5	1003.5
6	578.5	578.5	301	301	55	0	277.5	277.5	942.5	942.5	665	665	726	726	1003.5	1003.5
7	856	856	578.5	578.5	277.5	277.5	0	55.0	665	665	942.5	942.5	1003.5	1003.5	1281	1281
8	856	856	578.5	578.5	277.5	277.5	55.0	0	665	665	942.5	942.5	1003.5	1003.5	1281	1281
9	1281	1281	1003.5	1003.5	942.5	942.5	665	665	0	55	277.5	277.5	578.5	578.5	856	856
10	1281	1281	1003.5	1003.5	942.5	942.5	665	665	55	0	277.5	277.5	578.5	578.5	856	856
11	1003.5	1003.5	726	726	665.0	665	942.5	942.5	277.5	277.5	0	55.0	301	301	578.5	578.5
12	1003.5	1003.5	726	726	665.0	665	942.5	942.5	277.5	277.5	55	0	301	301	578.5	578.5
13	942.5	942.5	665	665	726	726	1003.5	1003.5	578.5	578.5	301	301	0	55	277.5	277.5
14	942.5	942.5	665	665	726	726	1003.5	1003.5	578.5	578.5	301	301	55	0	277.5	277.5
15	665	665	942.5	942.5	1003.5	1003.5	1281	1281	856	856	578.5	578.5	277.5	277.5	0	55
16	665	665	942.5	942.5	1003.5	1003.5	1281	1281	856	856	578.5	578.5	277.5	277.5	55	0

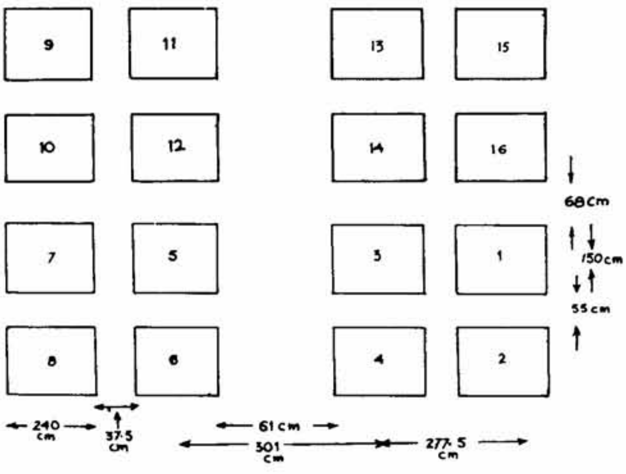


Fig. 2—Dimensions of looms and passages in a loom shed

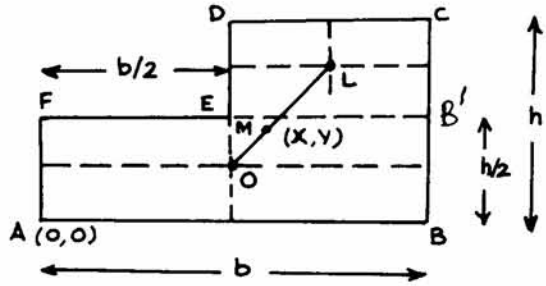


Fig. 3—Location of weaver for hexagonal layout of looms

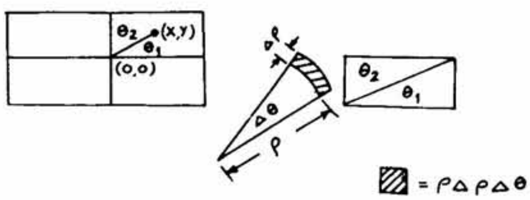


Fig. 4—Straight movement of weaver in a rectangular layout of looms

The weaver can be stationed at M. But this is not the best position since he may not be able to control the extreme looms with the same degree of supervision.

Second method—Termed as single-facility rectilinear minimax method[1], this enables the location of the weaver in any type of set-up arranged in columns or rows, or both. This method is of more relevance to a problem where quick service or convenient access is more important than minimizing long-term total costs. Here also, one has to consider a (0, 0) coordinate point at one edge of the hexagon or rectangle and then find the coordinates of each and every loom. Let the coordinates of the looms be (a_i, b_i), then the following algorithm can be stated:

$$\left.\begin{array}{ll} C_1 = \min(a_i + b_i), & C_2 = \max(a_i + b_i) \\ C_3 = \min(-a_i + b_i), & C_4 = \max(-a_i + b_i) \end{array}\right\} 1 \leqslant i \leqslant m$$

$$C_5 = \max(C_2 - C_1, C_4 - C_3)$$

where m is the number of looms.

Then the location point will be on the line joining the points

$$(\overset{*}{X}, \overset{*}{Y}) = \tfrac{1}{2}(C_1 - C_3, C_1 + C_3 + C_5)$$

$$(\bar{X}, \bar{Y}) = \tfrac{1}{2}(C_2 - C_4, C_2 + C_4 - C_5)$$

In this method, the degree of supervision is the same for the two extreme points because the calculation is based upon the maximum and minimum distances moved by the weaver. The minimax location method minimizes the function

$$f(X, Y) = \max(X - a_i + Y - b_i) \quad 1 \leqslant i \leqslant m.$$

The minimum value of the function is $C_5/2$.

In appendixes A and B some results are shown for 8- and 16-loom distance matrices.

Movement of Weaver

The pattern of movement of the weaver depends upon the layout of looms controlled by him. A straight-line movement is possible only when the weaver is assigned a group of looms arranged in a row or in a column; otherwise, a rectilinear movement takes place.

Straightway movement—The expected distance $E(D)$, moved by the weaver for a certain breakdown point from the centre, and the corresponding expected movement time $E(T)$ are determined as follows:

Let a weaver be in charge of some looms arranged row-wise (Fig. 4) and let the area covered by the looms be bh. Let the weaver be situated at centre (0, 0) position. If the weaver moves to a point (X, Y) straightway, let the distance from (0, 0) to (X, Y) be ρ and let the straight line make angles θ_1 and θ_2 with X and Y axes respectively. Now let the weaver move to a position $(X+\Delta X, Y+\Delta Y)$ with a length $\rho+\Delta\rho$ and making an angle $\theta+\Delta\theta$, then the area covered by the weaver from (X, Y) to $(X+\Delta X, Y+\Delta Y)$ is $\rho\Delta\rho\Delta\theta$. The probability that this small area will lie in the rectangle area $A(=bh)$ is

$$p(\Delta a) = \frac{\Delta a}{A} = \frac{\rho\Delta\rho\Delta\theta}{bh}$$

The probability that the weaver will move that small distance is

$$p(D) = p(\Delta a) = \frac{\rho\Delta\rho\Delta\theta}{bh}$$

Therefore, the expected distance moved for a breakdown from the location point is

$$E(D) = \int_0^{D_{\max}} D\,p(D) = 8\int_0^{\pi/4}\int_0^{(b/2)\sec\theta} \frac{\rho^2 d\rho\Delta\theta}{bh}$$

$$= 4\left[\int_0^{\theta_1}\int_0^{(b/2)\sec\theta_1}\frac{\rho^2 d\rho\Delta\theta_1}{bh} + \int_0^{\theta_2}\int_0^{(h/2)\sec\theta_2}\frac{\rho^2 d\rho\Delta\theta_2}{bh}\right]$$

Here $\theta_1 = \tan^{-1}\frac{h}{b}$, $\theta_2 = \tan^{-1}\frac{b}{h}$

$$\therefore \mathrm{E}(D) = 4\left[\int_0^{\tan^{-1}(h/b)}\int_0^{(b/2)\sec\theta_1}\frac{\rho^2 d\rho\Delta\theta_1}{bh} + \int_0^{\tan^{-1}(b/h)}\int_0^{(b/2)\sec\theta_2}\frac{\rho^2 d\rho\Delta\theta_2}{bh}\right]$$

and $\mathrm{E}(T) = \frac{2}{V}\mathrm{E}(D)$

where V is the speed of weaver.

The results of this type of movement for 8 looms are shown in App. C.

Rectilinear movement[2]—To find out E(D) and E(T) for this movement, three cases—(a), (b), (c)—on different layouts are discussed:

(a) Square area covered by loom (Fig. 5a): If the weaver moves from (0, 0) to (X, Y), then the distance moved $D = |X| + |Y|$

and $\mathrm{p}(D) = \frac{dx\,.\,dy}{4\gamma^2}$

$$\text{Then}\quad \mathrm{E}(D) = \int_0^{D_{\max.}} D\,\mathrm{p}(D) = \int_0^{D_{\max}} (X+Y)\,\mathrm{p}(D)$$

$$= \int_0^{2\gamma}\int_0^{2\gamma}(X+Y)\frac{dx\,.\,dy}{4\gamma^2} = \gamma$$

$$\therefore \mathrm{E}(T) = \frac{2}{V}\gamma$$

(b) Rectangle area covered by looms (Fig. 5b):

Here $\mathrm{p}(D) = \frac{dx\,.\,dy}{bh}$

$$\mathrm{E}(D) = \int_0^{D_{\max.}} D\,\mathrm{p}(D)$$

$$= 4\int_0^{b/2}\int_0^{h/2}(X+Y)\frac{dx\,.\,dy}{bh} = \frac{b+h}{4}$$

$$\mathrm{E}(T) = \frac{2}{V}\frac{(b+h)}{4}$$

(c) Hexagonal area covered by looms (Fig. 5c):

Here $D = |X| + |Y|$

and area ABCDEF $= bh(1-k/2)$

$$\mathrm{p}(D) = \frac{dx\,.\,dy}{bh\left(1-\frac{k}{2}\right)}$$

$$\mathrm{E}(D) = \int_0^{D_{\max.}} D.\mathrm{p}(D)$$

$$= 2(2-k)k\int_0^{b/2}\int_0^{h/2}(X+Y)\frac{dx\,.\,dy}{bh\left(1-\frac{k}{2}\right)} = \frac{k(b+h)}{4}$$

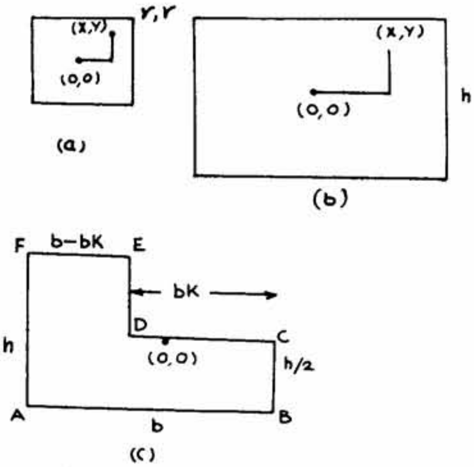


Fig. 5—Rectilinear movement of weaver in different layouts of looms [(a) square; (b) rectangular; and (c) hexagonal]

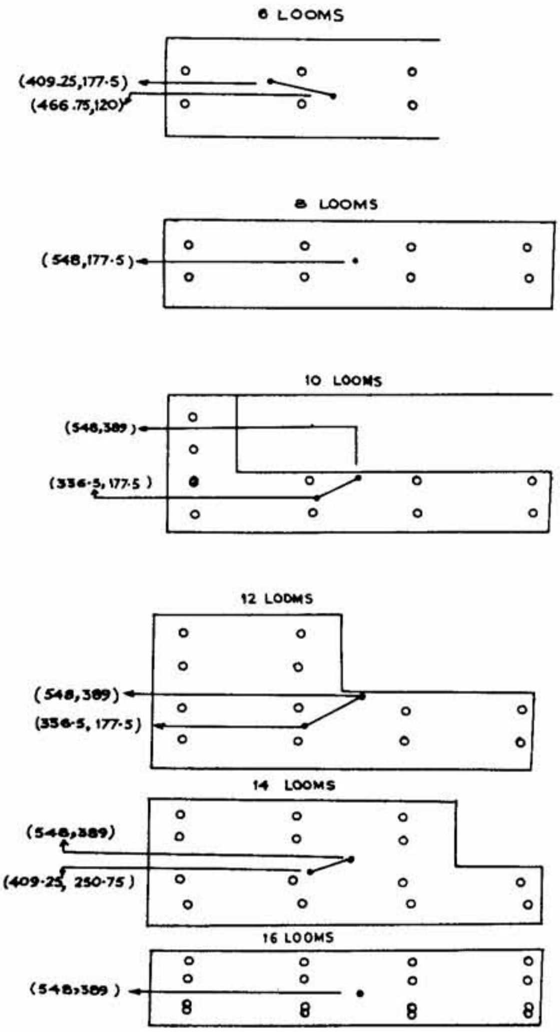


Fig. 6—Best layout and location point for weaver for 6, 8, 10, 12, 14 and 16 looms

Table 2—E(*D*) and E(*T*) on the Most Suitable Layout*

No. of looms	E(*D*) ft	E(*T*) s
6	6.04	3.02
8	5.08	3.81
10	17.34	8.67
12	16.43	8.22
14	15.78	7.89
16	17.53	8.76

*Fig. 6

The results of this type of movement with 8 looms are shown in App. D.

After finding out E(*D*) and E(*T*) for loom groups with different layouts, one can find the most suitable layout which gives the minimum E(*D*) and E(*T*). The best layout is shown in Fig. 6 with the location point; Table 2 shows the minimum E(*T*) and E(*D*) for this layout.

Conclusions

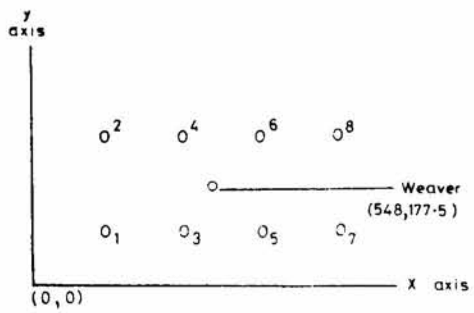
From the distance matrix, the weaver's location on every layout consisting of 6, 8, 10, 12, 14 and 16 looms is found and the average expected time to move for servicing from the location point to the breakdown point is determined. Thus the most suitable layout which gives minimum expected time can be found and used for assigning looms to a weaver. Weaver location point and expected distance moved by him do not depend on the number of looms but on the floor area occupied by the looms.

References

1 Richard L Francis & John A White, *Facility layout and location—An analytical approach* (Prentice Hall, New Jersey) 1974, 380.

2 Hillier F S & Liberman G J, *Introduction to operations research* (Holden Day, San Francisco) 1967, 337.

Appendix A: Location of Weaver for 8 Looms



From the distance matrix, the coordinates of the following 8 looms are found:

Loom 1 = (120, 150)   Loom 2 = (120, 205)
Loom 3 = (397.5, 150), Loom 4 = (397.5, 205)
Loom 5 = (698.5, 150), Loom 6 = (698.5, 205)
Loom 7 = (976, 150),   Loom 8 = (976, 205)

then

$C_1 = \min(a_i + b_i) = 270,$

$C_2 = \max(a_i + b_i) = 1181$

$C_3 = \min(-a_i + b_i) = 826,$

$C_4 = \max(-a_i + b_i) = 85$

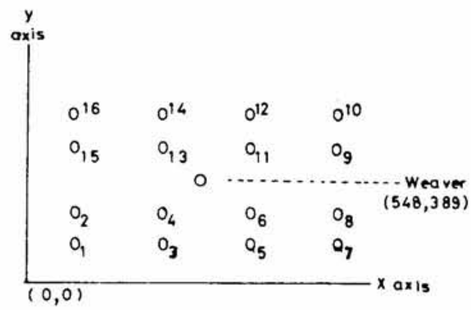
$C_5 = \max(C_2 - C_1, C_4 - C_3) = \max(911, 911) = 911$

$$\text{1st point} = (X^*, Y^*) = \tfrac{1}{2}(C_1 - C_3, C_1 + C_3 + C_5) = \tfrac{1}{2}(1096, 355) = 548, 177.5$$

$$\text{2nd point} = (\bar{X}, \bar{Y}) = \tfrac{1}{2}(C_2 - C_4, C_2 + C_4 - C_5) = \tfrac{1}{2}(1096, 355) = 548, 177.5$$

Both the points are the same. So the weaver's location is just at the middle according to the distance matrix.

Appendix B: Location of Weaver for 16 Looms



From the distance matrix, the following coordinates for the 16 looms are found:

Loom 1 = (120, 150),   Loom 2 = (120, 205)
Loom 3 = (397.5, 150), Loom 4 = (397.5, 205)
Loom 5 = (698.5, 150), Loom 6 = (698.5, 205)
Loom 7 = (976, 150),   Loom 8 = (976, 205)
Loom 9 = (976, 573),   Loom 10 = (976, 628)
Loom 11 = (698.5, 573), Loom 12 = (698.5, 628)
Loom 13 = (397.5, 573) Loom 14 = (397.5, 628)
Loom 15 = (120, 573), Loom 16 = (120, 628)

then $C_1 = 270$, $C_2 = 1604$, $C_3 = -826$, $C_4 = 508$ and $C_5 = 1334$

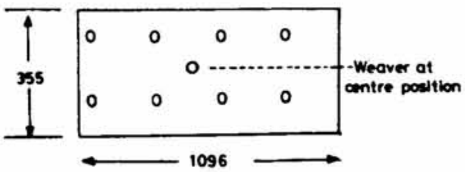
1st point $= (X^*, Y^*) = (548, 389)$.

2nd point $= (\bar{X}, \bar{Y}) = (548, 389)$

Both the points are the same, so the weaver's location is just at the middle point according to the distance matrix.

By this way the weaver's location point can be calculated in 6, 8, 10, 12, 14 and 16 looms in different layouts. Then the expected time taken by the weaver for a breakdown servicing can be found out in all the looms with different layouts. It will therefore be possible to ascertain the correct layout of looms which will allow the weaver to move a minimum distance with a minimum expected time for a breakdown.

Appendix C: Calculation for Expected Time with Straightway Movement for 8 Looms



According to the formula discussed earlier,

$\theta_1 = \tan^{-1} h/b = \tan^{-1} 355/1096 = 0.3239 = 17°57'$

$\theta_2 = (90° - 17°57') = 72°3'$

$$E(D) = 4\int_0^{\theta_1}\int_0^{(b/2)\sec\theta_1} \frac{\rho^2\, d\rho\, \Delta\theta_1}{bh} + \int_0^{\theta_2}\int_0^{(h/2)\sec\theta_2} \frac{\rho^2\, d\rho\, \Delta\theta_2}{bh}$$

$$= \frac{1}{6bh}\left[\left\{\frac{\sin\theta_1}{2\cos^2\theta_1} + \frac{1}{2}\log(\tan\theta_1 + \sec\theta_1)\right\}b^3 + \left\{\frac{\sin\theta_2}{2\cos^2\theta_2} + \frac{1}{2}\log(\tan\theta_2 + \sec\theta_2)\right\}h^3\right]$$

$$= \frac{1}{6bh}[0.23b^3 + 5.41h^3]$$

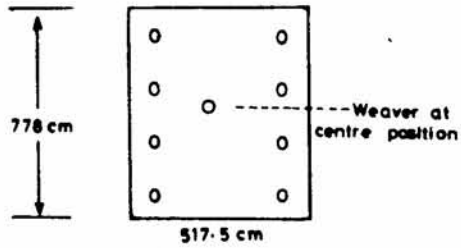
$$= \frac{0.23\times(1096)^3 + 5.41(355)^3}{6\times 1096\times 355}$$

$$= 232.5624\,\text{cm} = 7.63\ \text{ft}$$

$$E(T) = \frac{2}{V}\times 7.63\,\text{ft} = \frac{2}{4}\times 7.63\,\text{s} = 3.81\,\text{s}$$

Suppose the weaver's performance rating is normal, i.e. 100%, then V (weaver's speed) = 4 ft/s.

Appendix D: Calculation for Expected Time with Rectilinear Movement for 8 Looms



According to the formula derived earlier for rectilinear movement for a rectangle

$$E(D) = \frac{b+h}{4} = \frac{778+517.5}{4} = 10.63\,\text{ft}$$

∴ $E(T)$ at worker's performance level at 100%

$$= \frac{2}{4}\times 10.63 = 5.32\,\text{s}$$

So with the given distance matrix, the layout of 8 looms should be on a straightway movement basis because that gives the lowest $E(T)$ and $E(D)$. $E(T)$ and $E(D)$ mainly depend on the floor area covered by the looms. Hence $E(T)$ and $E(D)$ can be calculated for 6, 8, 10, 12, 14 and 16 looms in different layouts and it is possible to find out the most suitable layout, which is given in Fig. 6.