Mansoura Engineering Journal, (MEJ), Vol. 23, No. 3, September 1998.

Rating and Adjacency Problems in Facility Layout Construction

مشاكل التقرير و التجاور في إنشاء تخطيطي المنظومات

Hassan A. M. Soltan
Dept. of Prod. and Mech. Design Eng.,
Faculty of Engineering, Mansoura University, Mansoura, Egypt.
<hsoltan@mum.mans.eun.eg>

ملخص

معظم الأساليب المختصة بتخطيطي الأنظمة تحاول تصغير تكاليف مناولة المواد أو تعظيم علاقة التجاور الخاصة أو تصغير دالة ثنائية توازن الهدفين. في أغلب الأحيان يعتمد التصميم على الاتجاه الذي يعين الأقسام أو الماكينات لمواقع موجودة على شبكة مقسمة. هذه الدراسة تختص بحالة الطابق الواحد وتقدم أسلوب كشاف ذات مرحلتين. المرحلة الأولى تختص بتقدير العلاقات الكمية و الغير كمية و دمجها في مركبة واحدة باستخدام دالة تعظيم بمساعدة نظام تقدير. المرحلة التالية تختص بالإنشاء باستخدام إجراء، بنى على أساس نموذج النقل في شكل خاص، لحل مشكلة التجاور و التحديد الاستكشافي لمواقع الأقسام (أو الماكينات) والتي يمكن تبادلها للتحسين فيما بعد. وقدم إجراء آخر، بنى على أساس نموذج التخصيص الخطى، لحل مشكلة التجاور بأسلوب تراكبي وذلك بتعديل الصيغة المقترحة للنموذج الأول. وتتضح أهم ميزة للأسلوب المقترح في التغلب على قيود عدد الأقسام و العلاقات الكمية و الغير كمية و الذي يمكن أن يجعله مقبولاً من قبل الممارسين في مختلف المجالات. والأكثر من ذلك أنه يمكن أن يغذى أساليب أخرى لتقليل الجهد المبذول في إنشاء التخطيطات الضخمة ذات العلاقات المتعددة.

Most of the facility layout approaches attempt to minimize material handling cost, maximize special closeness, or minimize a two-component function weighting both objectives. The most often nsed design approach assigns facilities to locations on a discrete divided grid. Considering the single floor problem, this study presents a two-stage heuristic approach. First is the rating stage using a *maximization function*, assisted by a *rating system*, proposed to integrate objective and subjective relationships into one component. Second is the construction stage using a procedure, based on a special *Transportation Model*, proposed to solve the facility adjacency problem and heuristically locates the facilities with tentative trade offs. Also, another procedure based on *Linear Assignment Model* is presented for solving the adjacency problem through superimposing sub-layouts. The latter procedure slightly modifies the formulation proposed for the first. The salient advantage of the proposed approach appears in overcoming the limitations on the number of facilities and objective or subjective relationships which may attract the practitioners in different areas. Moreover, it can be fed into as an integral part of other approaches to minimize the effort consumed in constructing large layouts with multiple relationships.

(FACILITY; LAYOUT; WEIGHTING; RATING; MATERIAL HANDLING; ADJACENCY; TRANSPORTATION; ASSIGNMENT; GRID; OBJECTIVE/SUBJECTIVE RELATIONSHIPS; CONSTRUCTION/IMPROVEMENT)

1. Introduction

Generally, for a large manufacturing or service plant, the facility layout problem is the determination of most effective arrangement of the physical facilities therein under specific working conditions. It could be formulated for departments, cells, or machines. The main objective of the problem is to minimize the cost of material handling system in the presence of constraints resulting due to several objective and subjective factors. Bozer and Meller (1993) summarizes different definitions of the layout problem. The problem becomes more complicated with irregular shape facilities, because it adds the task of minimizing the dead space. The problem has been modelled and solved through mathematical and heuristic approaches which can be classified into three categories, construction, improvement, and hybrid construction/improvement (Kusiak and Heragu 1987, Yaman et al. 1993, Welgama and Gibson 1993). Due to the variety of interacting factors, the problem maintains a complex nature and the solution constitutes a difficult task in spite proposing many approaches. Therefore the problem is not settled eventually and most of the proposed approached don't attract practitioners especially when they have a large number of facilities.

The problem has been modelled in different mathematical approaches such as quadratic assignment (Lawler 1963, Kusiak and Heragu 1987), quadratic set-covering (Bazaara and Goode 1975), and graph theory (Foulds and Robinson 1978, Al-Hakim 1991, Hassan and Hogg 1987). Earlier, most often used model is the *Quadratic Assignment Problem* (QAP), which assigns a number of facilities to an available number of locations on a divided rectangular grid such that a cost function is minimized (Yaman et al. 1993, Welgama and Gibson 1993, Askin and Standridge 1993). Several solution procedures for such QAP are detailed in Bazaara and Goode (1975), El-Rayah and Hollier (1970), and Kusiak and Heragu (1987). As a result or input, irregular shapes for facilities weaken the solution of QAP on a discrete grid. As an attempt to deal

Accepted September 27, 1998

with such point of weakness, Heragu (1990) and Heragu and Kusiak (1990) developed a continual plane model.

However, the exact optimum approaches are based on branch and bound or cutting plane techniques and limited to small problems (Welgama and Gibson 1993). Hence, it is found impractical to search the problem solution optimally. Therefore, heuristics were developed to overcome these limitations. The most earlier and popular heuristics were developed in prominent packages such as CORELAP by Lee and Moore 1967, ALDEP by Seehof and Madelheim 1967, CRAFT by Buffa et al.1964, and PLANET by Apple and Deisenroth 1972: see Riggs (1976), Hales (1984) and Yaman et al. (1993). The first two packages are constructive while the latter are improving. Hence, many computer aided approaches appeared (Lewis and Block 1980, Khator and Moodie 1984).

Construction approaches can be further categorized as graph theory based approaches and conventional approaches (Welgama and Gibson 1993). Also many heuristics are based on Graph theory. Foulds and Robinson (1978) presented a graph theory based heuristic and Al-Hakim (1991) applied the graph theory to his two improvement heuristics. Although this theory is conducted to heuristics, it maintains many disadvantages which were discussed in Hassan and Hogg (1991).

Recently, Kaku et al. (1991) developed a hybrid construction/improvement heuristic approach called KTM. Yaman et al. (1993) described a sorting construction heuristic divided into three modules and directed towards minimizing the traveling distances between facilities. Welgama and Gibson (1993) presented a construction algorithm generating machine layout on a continuum, minimizing the material flow cost. This specific algorithm considers some practical aspects and can be extended to general facility layout problem.

More recently, Meller and Gau (1996) presented a sample of recently published layout algorithms by authors and objective functions from 1988 to 1994 and highlighted different review papers including their recent review paper. Moreover, they discussed and examined the three traditional layout objective functions with respect to material handling costs providing a physical interpretation of the weights in the weighted-criteria facility layout two-component objective function. Also, they developed an objective function based on a basic material handling cost structure. Meller and Bozer (1996) considered both single floor and multi floor problems in an improvement type algorithm based on simulated annealing (the relationship between combinatorial optimization and statistical mechanics); in other words, this approach considers an expanded set of facility exchange.

However, the literature proved that there is no efficient algorithm solves the problem optimally and the experimental refinement is a must and most of the current algorithms do not attract the practitioners. The complications result from the variety of factors that interact in the layout problem. The purpose of this paper is to provide a new comprehensive approach which comprises two stages. First, it analyzes the facility relationships through a criterion combines the existing relationships in a single numerical component and then solves the adjacency problem in constructing a layout. The problem formulation is mainly based on the transportation and linear assignment models.

2. Factors of the Layout Problem

The plant layout problem is subjected to a large variety of factors which are dependent upon the prospective layout, nature of the planned process, material handling system, and other system constraints (such as limited type and number of machinery). The material handling costs is the most common factor, since it explains about 20% to 50% of the total operating costs (Meller and Gau 1993). Such factors are scattered in the literature (Yaman et al. 1993, Askin and Staudridge 1993) but, here, they will be comprehensively organized. Generally, the main factors are

1. Number of products,
2. Number of units of each product,
3. Number of facilities (departments, workcentres, or machines) of the plant,
4. Sequence of processes of each product (forward and backward movements),
5. Facility sizes,
6. Facility shapes (regular/irregular and dimension limitations),
7. Space availability,
8. Special closeness relationships between facilities. For example two or more facilities should be adjacent because they share fixed or moveable facilities or due to other requirements. The system *A, E, I, O, U, X* is often used to rate the importance of such closeness (Riggs 1976). These rates can be carefully assigned some arbitrary numeric values. (Yaman et al. 1993, Askin and Standridge 1993).

There are more specific factors that may make the problem more complicated. Some of them depend on the plant location and nature of resources and transportation from/into the plant while others depend on the prospective material handling system, plant construction. and the service utilities. This category comprises

1. External transportation system such as rail roads, routes, and resource accesses. This may restrict the locntion of shipping, receiving, and other facilities,
2. Aisle shapes and locations (they may be specificd in advance). They are preferred to be straight as possible in regular rectangles with easy intersections,
3. Building height. story, pairs. and flow pattern,
4. Services. which are often eonsidered fixed facilities, such as heating-cooling, ventilation. air conditioning, illumination. recycling networks. water resource, and power resources. These services may restrict the location of one or more faeilities according to their requirements.
5. Costs sııch as material handling cost which depends on the distance and number of trips between facilities (backward motion may weight over forward motion) and other costs.

The planner may embed other factors to the plant and facility layout problem. Intuitively, the cited factors comprise subjective and objeetive factors and some of them may be related to each others. For example, the special closeness relationships may result from the location of services and/or nature of the available material handling system. The facility relationships are often exhibited using a tabular *from-to form*.

3. Proposed Methodology

The methodology comprises a numerical function for rating facility relationships and two different procedures for solving the adjacency problem. The first procedure is based on the transportation model and the second is based on the linear assignment model.

3.1 Numerical Rating Function

Both objective and subjective relationships between facilities will be numerically rated and combined into a single function. It is assumed that a plant consists of n facilities such that facilities i and j joint through an objective relationship. O_{ij}, and mutualize a subjective relationship, S_{ij}. An extension for the aumber of relationships will be discussed later.

(a) Rating Objective Relationships

The objective may be minimizing the material handling cost: in other word, facilities neighbor as possible those related by maximum handling requirements such as number of trips per time or number of handling facilities. Suppose thnt the number of trips is found effective, it can be rated simply in three ways:

-Base number rating- A number of trips is rated as a base for all entries. For example every ten trips are rated one and so on;

-Relative rating- All entries are related to the maximum entry;

-Density rating- Imagine O. number of trips, to be a random variable with density function $f(a)$ which may follow a distribution such as linear or exponential. Let b a constant and assume an exponential distribution, as shown in Fig. 1.

$$f(o)=\begin{cases} be^{o} & 0\le o\le o_{\max} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Then, rating of number of trips between facilities can be approximated by the cumulative area, under $f(o)$, encompassed by 0 and O_{ij}, formally

$$R(O_{ij})=\int_0^{O_{ij}} f(o)do = b(e^{O_{ij}}-1) \quad (2)$$

which indicates that the maximum rating will be 100%. It is found more systematic way consolidating for the incremental effect of the number of interfacilities trips per unit time. Of course, the planner may resort to a combination between the three ways.

(b) Rating Subjective Relationships

The objective may be touching the facilities according to their mutual special closeness. This paper presents a term named ***importance horizon***, H, for the closeness relationship. It is a random variable with density function $f(h)$ which may follow a distribution such as linear or exponential. This horizon is divided into a number of equal distances according to the number of importanee levels. Suppose that we are concerned with the traditional six levels A, E, I, O, U, and X, which decay in that order. The level X is assigned a very large negative value while the others are assigned contiguous areas under $f(h)$, which is assumed exponential, as shown in Fig. 1.

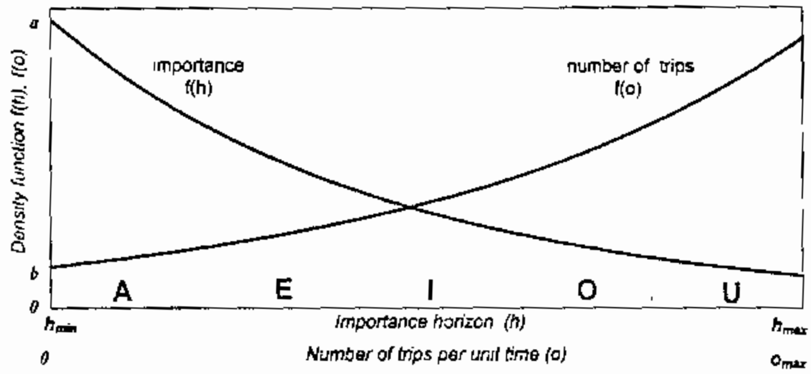


Fig. 1 Rating special closeness and number of trips using expouential distributions.

Assume that a is constant. h_{min} and h_{max} are the limits of the horizon, and h_1 and h_2 are the limits of an importance, then

$$f(h) = \begin{cases} ae^{-h} & h_{min} \le h \le h_{max} \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

Hence, numerical rating of importance of mutual closeness is approximated by the area encompassed by h_1 and h_2, formally

$$R(S_{ij}) = \int_{h_1}^{h_2} f(h)dh = a(e^{-h_1} - e^{-h_2}) \tag{4}$$

The parameters of both equations, in addition to the distribution type, are completely heuristic determinants; but they represent a basic relaxation to the problem of rating the closeness importance. Here, values of h_{min}, h_{max}, and step are recommended "0", "5", and "1" respectively. The time and experience, of course, will find out different alternatives. Other subjective relationships can be rated in a similar way.

The efficiency of this rating system may diminish when integrated into the system defined for the objective relationships. Suppose that a relationship such A exists due to sharing an expensive equipment, then farness should be ***penalized*** relative to the cost of duplicating equipment. This penalty can be estimated in different ways such as ***multiples*** of interfacilities material handling cost (or number of trips) which replaces such subjective relationship. By this way, most of the subjective relationships can be replaced. A fixed facility out the plant can be included as a zero area facility. It is obvious that a relationship such X always separates by its large negative value.

(c) Final Weighted Rating

Suppose that the current objective relationship simulates the number of trips per time and the current subjective relationship simulates the special closeness. Hence, the total rating between facilities i and j is

$$R_{ij} = w_{ij} R(O_{ij}) + (1 - w_{ij}) R(S_{ij}) \tag{5}$$

where w_{ij} is the weight awarded to the objective relationship between facilities i and j. Such weight may be constant for all facilities. It may be neglected, if both are equally weighted. A useful concept, the ***central facility***, is monitored. It may be defined in many ways (Askin and Standridge 1993), whilst here it will be defined as the facility which registers maximum global rating, GR_i, where

$$GR_i = \sum_{j=i+1}^{n} R_{ij} \tag{6}$$

This facility, actually, has significant relationships with one or more of other facilities. For that concern, we should ignore the X relationship, because its large negative value would lead to fallacious global ratings. Also, the rating mean and standard deviation are two important indicators for the benefit of central facility;

therefore little coefficient of variation (CV) should not be neglected. However, for nearly uniform facility shapes and uniform available space, the digit of $n/5$ is proposed as a guide for the maximum number of central facilities since in such a case when having at least five facilities, a central facility could be attached in four sides.

3.2 Assumptions

A planner may impose several assumptions for simplification or other purposes. The most significant assumptions include

1. The problem is formulated with a static deterministic environment,
2. Material handling cost between facilities is a direct function of the number of trips per time and traveled distance,
3. Distance between facilities is an output parameter if another alternative is used, as an inpat, such as number of trips per time,
4. Facilities are square or rectangular in shape.
5. The flow pattern may be imposed in advance such as spine-oriented straight line.

A fixed facility relationship between two or more facilities should be coded significantly. In other words, if a facility is restricted by another facility, they should be manipulated as one area. These codes choice depends on the user, they may be numbers and/or letters displaying positions such as Right/Left or Up/Down.

3.3 Problem Formulation and Solution

Most of the facility layout approaches attempt to minimize material handling cost (distance-based), maximize special closeness (subjective adjacency-based), or minimizing weighted two-component objective function: see Meller and Gau (1996) for details. The salient disadvantage of the third objective function appears when an additional factor interacts which, in turn, complicates the task of relating a relative weighting factor. Here, the objective will be to construct a layout which maximizes special closeness and minimizes material handling costs. This is implicitly equivaleut to minimizing the traveling distances between the facilities according to their total mutual rating. The derived ***numerical rating function*** combines both objectives into a single-component maximization function. Here, it is proposed to formulate the problem as

$$\text{Maximize} \quad \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} x_{ij} R_{ij} \tag{7}$$

Subject to

$$\sum_{j=i+1}^{n} x_{ij} \le \theta_i \quad \text{for } i\text{'s} \qquad \text{as sources} \tag{8}$$

$$\sum_{i=1}^{j-1} x_{ij} = 1 \quad \text{for } j\text{'s} \qquad \text{as destinations} \tag{9}$$

$$x_{ij} = \{0,\ 1\} \tag{10}$$

This linear programming model can be reformulated as a ***special transportation model*** (maintains an assignment property) as proposed iu Table 4. Thus making it easy to provide a near optimal solution. The decision variable x_{ij} is set to 1 if facilities i and j should be adjacent, otherwise it is set to 0. The parameter θ_i (a digit ≥ 0; variable/constant) is proposed. guided by GR_i, to express the number of facilities that could be adjacent to facility i especially when i is central; this also depends on the facility space requirements. This problem assigns facilities to facilities, therefore, it is not a lower bound on QAP which assigns facilities to locations (Askin and Standridge 1993, Yaman et al. 1993, Welgama and Gibson 1993).

The regular transportation model (balanced minimization form) solves the adjacency problem. Hence, a rectangular draw (divided grid) is suitable for realizing the attachment between facilities as shown in Fig. 2. Here, the question would be Right/Left or Up/Down? Which also may be restricted by fixed facilities. The facilities which are restricted by fixed facilities are located directly with minor switches. The locating process is treated with some trade offs maintaining adjacent facilities with maximum rates.

The final rectangular realization is converted to a space diagram showing facility space and shape requirements, aisles, and special fixed facilities. If the flow pattern and facility shapes are specified as input, the space relationship becomes more deterministic but it may add to difficulty. The refinement may need to facility switching which must be made with a manner keeping the shape integrity and adjacency of facilities. The planner may be forced to pass an aisle between adjacent facilities, such decision should be made carefully to maintain a compatible degree of adjacency.

The main principal of the ***alternate procedure*** is to solve a sequence of ***linear assignment problems*** which can be dealt with using ***Hungarian*** algorithm. Hence, the right side of inequality 8 is modified to '=1' which removes the slack column and 'θ' column in Table 4 next. The original problem solution results in paired combinations (sub-layouts) of facilities such that the total rating is maximized (adjacency is maximized). Thereafter, a next smaller problem is solved for those combinations, and so on until reaching the final problem. Notice that after the problem reaches two or three combinations, it can be settled using the original rates of the peripheral facilities. A three combinations problem can be directly solved using the principal of central combination.

The mutual rates between each two combinations are estimated using eq. (12) next, therefore provisions should be taken for the undesirable relationships and exhibited on the assignment table. Assigned facilities or combinations are crossed row wise and column wise; that may lead to unassigned items in an iteration as shown in Table 5 (combination Y is the same as B).

Intuitively, a rate between two combinations is a direct function of the mutual rates between the facilities in both sides. For two-facility combinations, $C1$ (A and B facilities) and $C2$ (C and D facilities), the equivalent mutual rate is heuristically proposed as

$$R_{C1C2} = Max[(Max(R_{AC}, R_{AD}) + Max(R_{BC} + R_{BD})), (Max(R_{CA}, R_{CB}) + Max(R_{DA}, R_{DB}))] \qquad (11)$$

or generally for multi-facility combinations

$$R_{C1C2} = Max[\sum_{i \in C1} Max\{R_{ij}\}_{j \in C2}, Max \sum_{i \in C2} Max\{R_{ij}\}_{j \in C1}] \qquad (12)$$

At each iteration, this procedure locates the facilities in each combination under the resultant adjacency. It attaches each two combinations in a manner maximizing the rates between the facilities in both sides. Therefore attachments may force the planner to make some iterative switching without significant effect on the total rating in the final layout. The principal of central facility is used within each combination plot to reduce the expected number of switches. Also, the final results can be visualized using a divided grid and a space diagram showing the shape details. Also, this procedure is not a lower bound on QAP because it assigns facilities to facilities not facilities to locations.

3.4 Extension of Relationships

Suppose that a plant consists of n facilities such that facilities i and j joint through l objective relationships, $(O_1)_{ij}$, $(O_2)_{ij}$, …, $(O_l)_{ij}$ and mutualize m subjective relationships, $(S_1)_{ij}$, $(S_2)_{ij}$, …, $(S_m)_{ij}$. First, it is assumed that those relationships are rated and directed to the same objective. Hence, the total rating between facilities i and j is modified to

$$R_{ij} = w_{ij} \sum_{q=1}^{l} w_q R[(O_q)_{ij}] + (1 - w_{ij}) \sum_{t=1}^{m} w_t R[(S_t)_{ij}] \qquad (13)$$

where w_{ij} is the weight awarded to the objective relationship between facilities i and j; w_q weights O_q; and w_t weights S_t. However, ratings may be approximated in many ways, validating an algebraic sum, as followed in section (3.1). Both types of relationships should be rated and summed in a maximization direction.

4. Illustrative Manipulation

Suppose that we are encountered with the problem of constructing the layout which has the data shown in Table 1. Each tabular cell contains a letter expressing the special closeness importance and a number expressing the number of trips per hour between the departments. The A, E, I, O, U, X system is assumed for the special closeness.

Table 1 Initial from-to for special closeness and number of trips per h¯ur.

Dept.	1	2	3	4	5	6	7	8	9	10
1		A.30	X,0	U,10	I,25	E.10	I,5	O.15	U,15	E,25
2			E.5	I,20	I,15	O,25	U,5	A,20	E,30	U,15
3				O,10	E.15	I.30	A,5	E,15	I,10	I,15
4					O.15	E.15	U,10	U,10	U,5	O,5
5						A.10	U,10	E,20	U,5	O,5
6							O.15	O,30	A,30	I,5
7								E.10	I,15	I,20
8									E.10	U,10
9										X,10
10										
Shape	10*8	10*10	10*8	10*8	10*8	10*10	10*10	10*14	10*12	10*8
Area (mt^2)	80	100	80	80	80	100	100	140	120	80

The letter explains the importance of closeness relationship and the number explains the number of trips per hour.

The rating process is completed using the system proposed in section (3.1) as shown in Tables 2 and 3. The *Base number* and *density* ways are combined to rate the number of trips per hour: this to minimize the overflow in calculations. The results are registered in Table 4.

Table 2 Rating the number of trips.

No. of trips	05	10	15	20	25	30
Points *	0.5	1.0	1.5	2.0	2.5	3.0
Rate (%)	03	09	18	33	58	100

*Each 5 trips is assumed 0.5 point for O_{ij}; b=0.052

Table 3 Rating the special closeness.

Level	*A*	*E*	*I*	*O*	*U*	*X*
H **	1	2	3	4	5	---
Rate (%)	64	23	09	03	01	-M

**h_{min}=0; h_{max}= 5; step=1: a=1.006; M is large −ve

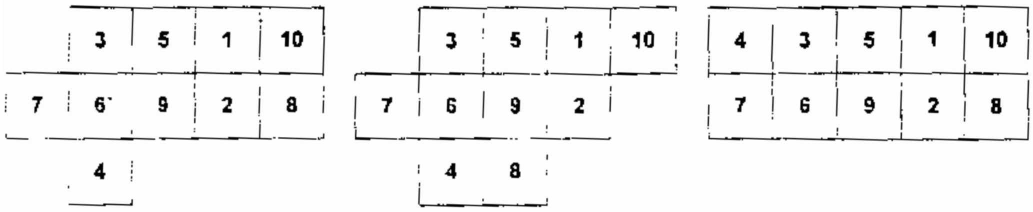
Table 4, which should be modified to a maximization transportation form, illustrates the final rating using Eq. 5 assuming that the objective and subjective relationships are equally weighted. Notice that the weight can be neglected when both relationships are equally weighted.

Table 4 Numerical rating (final %) from-to and statistical calculations.

Dept.	1	2	3	4	5	6	7	8	9	10	Slack	From
1	-M	164	-M	10	**67**	32	12	21	19	**81**	-	θ_1
2	**164**	-M	26	42	27	61	4	**97**	123	19	-	θ_2
3	-M	26	-M	12	41	109	67	41	18	27	-	θ_3
4	10	42	12	-M	21	41	10	10	4	6	-	θ_4
5	67	27	41	21	-M	73	10	56	4	6	-	θ_5
6	32	61	**109**	**41**	73	-M	**21**	103	**164**	12	-	θ_6
7	12	4	67	10	10	21	-M	32	27	42	-	θ_7
8	21	97	41	10	56	103	32	-M	32	10	-	θ_8
9	19	**123**	18	4	4	**164**	27	32	-M	-M	-	θ_9
10	81	19	27	6	6	12	42	10	-M	-M	-	θ_{10}
To	1	1	1	1	1	1	1	1	1	1	Sum-10	Sum
Sum	*406*	*563*	*341*	*156*	*305*	*616*	*225*	*402*	*391*	*203*	*Statistical calculations* for the *final ratings*	
Mean	*51*	*63*	*43*	*17*	*34*	*68*	*25*	*45*	*49*	*25*		
STD	53	54	32	14	27	49	20	35	60	26		
CV	*1.039*	*0.857*	*0.744*	*0.823*	*0.794*	*0.720*	*0.800*	*0.777*	*1.224*	*1.040*		

The slack column, in transportation table, should be assigned zeros after switching to the minimization equivalent. Any suitable transportation technique can be used to solve the regulated problem.

Table 4 indicates that department 6 suits the central position of the plant because it registers maximum total rating with minimum CV. Therefore, θ_6 could be assigned 4 (the sides of departments don't allow more) while other θ's could be assigued 4 or less (e.g. 2). The solution of the regular transportation problem is shown by bold cells on Table 4. Fig. 2-a shows a rectangular realization for the departmental adjacency which can be easily converted to a space diagram showing the aisles and shape requirements. It is obvious that department 6 is optimally positioned between departments 3, 5, 8, and 9, therefore department 8 could be switched as shown in Fig. 2-b with compatible total rating.



(a) Initial plot. (b) Switch dept. 8. (c) Switch dept. 4.

Fig. 2 Adjacency by transportation model.

However, the geometry of the available space and departments is an important determinant for the proposed switches. For instance, if the departmental geometry is completely uniform, it may be proposed to switch department 4 as shown in Fig. 2-c to minimize the dead space.

Table 5 and Fig. 3 summarize the results of the alternate procedure showing departmental assignments. The problem ends with three combinations X, Y, and Z which are superimposed using the rates of the peripheral departments.

Table 5 Iterative assignment combination analysis.

First Iteration			Second Iteration			Current
Comb.	Depts.	Center	Comb.	Depts.	Center	Switch
A	1.2	-	X	1.2.4.10	1	-
B	5.8	-	Y	5.8	-	5 with 3
C	6.9	-	Z	3.6.7.9	6	3 to X
D	3.7	-				
E	4.10	-				

Centers are determined by using eq. (6).

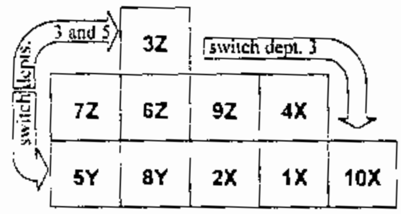


Fig. 3 Adjacency by assignment model.

The expected switching of department 3, in Fig. 3, is advantageous only when the space is limited. Also, departments 3 and 5 can be successfully exchanged. The resultant layout is different from that results from the first procedure with maintaining near total rates. However, the different between both procedures is dependent upon the value of 'θ' proposed for the first procedure.

5. Conclusions

The literature proved that the layout construction and improvement are combinatorial problems especially when the number of facilities and shape requirements increase. Therefore it is difficult to solve the problem optimally with out expecting future refinement whatever the approach used. A non-iterative and iterative construction procedures are presented for solving the adjacency problem with a manner reaching the best solution with minor switching as proved by the case manipulated. Also the presented *rating mechanism* reduces the problem parameters and addresses economical considerations of qualitative relationships by imposing the penalty principal. The problem is formulated in a different fashion which combines all problem objectives in a single function avoiding the objective weighting. Thus making it possible to accommodate a large variety of facility relationships and a large number of facilities.

Although the current procedures are based on the *transportation* and *assignment* models, they are considered simple mathematically based heuristics. Both procedures are not lower bounds on QAP which resorts to complicated computations. Therefore both are advised for practitioners using microcomputers. Further, practitioners may focus on reducing the duad space in the final layout which exhibits other considerations such as aisles and existing facilities or buildings. Such considerations can be manipulated by considering them on the model as basic facilities using specific codes. If aisles is not specified in advance, the resultant layout may be subjected to some facility switching. Moreover, the approach can be partially or completely integrated to other construction approaches to provide a starting solution for an improvement approach.

However, the facility layout problem could not be settled eventually and still needs to an extensive research work. From analysis view, it is recommended to resort to mathematically based heuristics. From practical view, it is recommended to empower the matter to a team work having practical and industrial experiences

Acknowledgments

The author thanks in particular Dr. Mohamed Sobeh Hossen and Dr. Said Frahat for providing a lot of helpful material. The author would like to acknowledge the proposal of Eng. Rania Mostfa and thank Eng. Mona Aalia and Eng. Asmaa Shaban due to their help in revising calculations.

References

Al-Hakim. L., "Two graph theoretic procedures for an improve solution to the facilities layout problem.." Int. J. Prod. Res., Vol. 29. No. 8, 1991.

Askin, R. G. and Standridge, C. R., Modeling and Analysis of Manufacturing Systems, John Wiley & Sons, Inc., New York, 1993.

Bazaara, M. S. and Goode. J. J.. "A cutting-plane for the quadratic set-covering problems," Oprs. Res., Vol. 23, No.1, 1975.

Bozer, Y. A. and Meller, R. D., "A reexamination of the general faeility layout problem," Technical Report 93-01, Department of Industrial Engineering, Auburn University, 1993.

El-Rayah, T. E. and Hollier. R. H., "A review of plant design techniques." Int. J. Prod. Res., Vol. 8. No. 3, 1970.

Foulds, L. R. and Robinson, D. F., "Graph theoretic heuristic for the plant layout problem," Int. J. Prod. Res., Vol. 16, No. 1, 1978.

Hales, H. L., Computer Aided Facilities Planning, Marcel Dekker, New York, 1984.

Hassan, M. M. and Hogg, G. L., "A review of graph theory application to the facilities layout problem," OMEGA, Int. J. Mgmt. Sci., Vol. 15, No. 4, 1987.

Hassan, M. M. and Hogg, G. L., "On eonstructing a block layout by graph theory," Int. J. Prod. Res., Vol. 29, No. 6, 1991.

Heragu, S. S., "Modeling the machine layout problem," Comp. & Ind. Engng., Vol. 19, No. 1-4, 1990.

Heragu, S. S. and Kusiak, A., "Machine layout: an optimization and knowledge-based approach," Int. J. Prod. Res.. Vol. 28. No. 4, 1990.

Khator, S. and Moodie, C., "Computer assisted plant layout using a graphics editor," Comp. & Ind. Engng., Vol. 8, No. 3, 1984.

Kusiak. A. and Heragu, S. S., "The facility layout problem," Eur. J. Oprl. Res.. Vol. 29, No.3, 1987.

Lawler, E. L., "The quadratic assignment problem," Mgmt. Sci., Vol. 9, No. 4, 1963.

Lewis, W. P. and Block, T. E., "On the application of computer aids to plant layout," Int. J. Prod. Res., Vol. 18, No.1, 1980.

Meller, R. D. and Bozer, Y. A., "A new simulated annealing algorithm for the facility layout problem." Int. J. Prod. Res., Vol. 34, No. 6, 1996.

Meller, R. D. and Gau, K.-Y., "Facility layout objective fnnetions and robust layouts," Int. J. Prod. Res., Vol. 34, No. 10, 1996.

Riggs, J., L., Production Systems: Planning, Analysis and Control, John Wiley & Sons, Inc., New York, 1976.

Yaman, R.; Gethin. D. T. and Clarke, M. J., "An effective sorting method for facility layout construction," Int. J. Prod. Res., Vol. 31, No.2, 1993.

Welgama, P. S. and Gibson, P. R., "A construction algorithm for the machine layout problem with fixed pick-np and drop-off points," Int. J. Prod. Res., Vol. 31, No.11, 1993.