

Design Technology for Layout

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Abstract

Layout decisions entail determining the placement of departments, work groups within the departments, workstations, machines, and stock-holding points within a production facility. The objective is to arrange these elements in a way that ensures a smooth work flow (in a factory) or a particular traffic pattern (in a service organization).

In our treatment of layout, we examine how layouts are developed under various formats (or work-flow structures). Our emphasis is on quantitative techniques, but we also show Examples(case study in The General Company For Cars Industry In Hilla) of how qualitative factors are important in the design of the layout. In manufacturing facilities are covered in this technical research. Design Technology will be employed to assist operation technology management in computer- aided process factory layout design. In this research we deal Design Technology Systems or(Techniques)are "Craft-Aldep- and Corelap) In the past, there were many techniques to design industrial plant layout. The most popular was CRAFT Computerize Relative Allocation Facilities Technique. However, the result from CRAFT was limited. The result of design showed only minimum total transfer cost between departments. As a result, the simulation technique is added to plant layout design to show more information about the design such as total time in system, waiting time, and utilization. and focus in research on the CRAFT that gives a heuristic method that uses a trip matrix including materials flow, transportation costs, and an initial block layout, and make a series of paired exchange of departments to find a better block plan with latest costs, to a chive strategic importance of factory layout through . In this research we have proposed a semi-heuristic optimization algorithm for designing optimal plant layouts in process-focused manufacturing/service facilities. Our proposed algorithm marries the well-known CRAFT with the Hungarian assignment algorithm. Being a semi-heuristic search, our algorithm is likely to be more efficient in terms of computer CPU engagement time as it tends to converge on the global optimum faster than the traditional CRAFT algorithm - a pure heuristic. We also present a numerical illustration of our algorithm.

Key Words: Facilities layout planning, Plant, load matrix, CRAFT, Hungarian

الخلاصة

تحدد قرارات الترتيب الداخلي للمصنع مساحات الاقسام، مجاميع العمل ضمن الاقسام، محطات العمل، المكائن، ونقاط المخزون من المواد تحت الصنع ضمن تسهيلات الانتاج، والهدف من ترتيب هذه العناصر بطريقة معينة لضمان تدفق العمل بمرونة (في المصنع) ونمط مرور عملي (في منظمات الخدمة). وفي معالجتنا للترتيب الداخلي للمصنع، سنختبر كيف ان الترتيب يُطور تحت صيغ مختلفة (او هياكل تدفق العمل). ومرحلتنا هي تقنيات كمية، لكن سنتم الاشارة الى ذلك بـ (دراسة حالة في الشركة العامة لصناعة السيارات في الحلة) وتوضح اهمية العوامل الكمية في تصميم الترتيب الداخلي للمصنع. وكيف ان تكنولوجيا التصميم ستساعد ادره تكنولوجيا العملية في عملية تصميم الترتيب الداخلي للمصنع بمساعدة الحاسوب. وفي هذا البحث سنتناول تحديداً تقنيات التصميم الداخل واشهرها تقنية التسهيلات الموقعية النسبية المحوسبة (CRAFT) ونتيجة التصميم بواسطة هذه التقنية هي لتخفيض كلف النقل الكلية بين الاقسام. وكننتيجة ستضيف تقنية المحاكاة للتصميم الداخلي معلومات أكثر حول التصميم كالوقت الكلي، وقت الانتظار، والاستخدام، وسيسلط الضوء في البحث على تقنية (CRAFT) التي تعطي طريقة مهيكله تستخدم مصفوفة تتضمن تدفق المواد، كلف النقل، والترتيب الأولي، وسلسلة من التبادلات الزوجية للاقسام لاجاد افضل خطة ذو الكلفة الأدنى للوصول الى الاهمية الاستراتيجية للترتيب الداخلي للمصنع، وسيتم اسخدام اللوغارتمية الهندسية لتطبيق تقنية (CRAFT) للحصول على كفاءة اسرع لعملية حساب تبادل الأزواج للاقسام وسيتم تقديم توضيح رقمي حول الخوارزمية وتم الوصول الى افضل ترتيب داخل اقسام الصنع للشركة المبحوثة.

الكلمات المفتاحية: تخطيط تسهيلات الترتيب الداخلي، المصنع، مصفوفة الحمل، خوارزمية التقييم الهندسية.

assignment algorithm

-Search Mythology: it was contented

1-Search Problem:

Plant layout problems can occur in a large number of ways and can have significant effects on the overall effectiveness of the production system. According to

Tompkins, since 1955, approximately 8% of the Gross National Product (GNP) has been spent annually on new facilities in the United States, and it is generally agreed that effective facilities planning can reduce material handling cost by at least 10 to 30%. The size of the investment in new facilities each year makes the field of facilities planning important. Current problem in The General Company for Cars Industry In Hilla. We consider a small, single-storied process-focused manufacturing plant with a rectangular shop floor plan having six different facilities.

2 . Objectives of the Search:

Some typical plant layout objectives are to

- Meet the economic demand: minimize investment in equipment and material handling cost General Company For Cars Industry In Hilla..
- Meet the requirement of product design and volume.
- Meet the requirement of process equipment and capacity: minimize overall production time; maintain flexibility of arrangement and operation; minimize variation in types of material handling equipment; facilitate the manufacturing process.
- Meet the requirement of quality of work life: provide for employee convenience, safety and comfort; facilitate the organizational structure.
- Meet the requirement of building and site constraints: utilize existing space most effectively.

3. Procedures of the Search:

Computerized Relative Allocation of Facilities Technique (CRAFT). The basic procedure is repeated a number of times resulting in a more efficient block layout every time till such time when no further cost reduction is possible. The final block layout is then printed out to serve as the basis for a detailed layout template of the facilities at a later stage.

FIRST: Literature Review

1. Concept of Facilities Planning and Plant Layout:

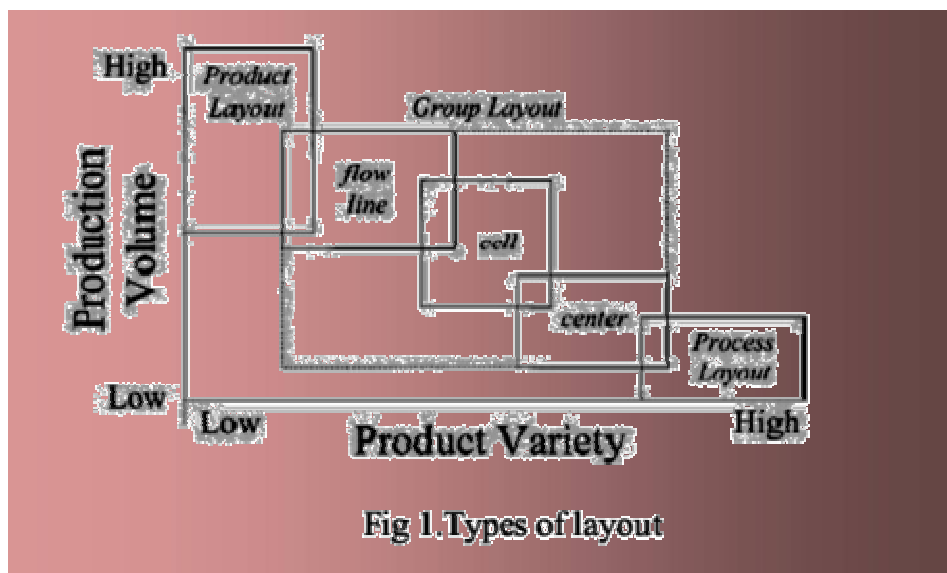
Facilities planning are a complex and broad subject that covers several disciplines. It involves civil, electrical, industrial and mechanical engineers, as well as architects, consultants, managers and urban planners.

According to Tompkins and White, facilities planning determine how an activity's tangible fixed assets best support achieving the activity's objective. Facilities planning can be divided into two components: facilities location and facilities design.

Facilities location is about placement of the facility on a specific plot of land with respect to customers, suppliers and other facilities. Facilities design consists of the facility systems design, the layout design and the handling systems design. The facility systems consist of the structural systems, the environmental systems, the lighting/electrical systems and safety systems. The layout consists of all equipment, machinery and furnishings within the building structure. The handling system consists of the mechanisms needed to satisfy the required facility interactions. For a manufacturing plant, the facilities layout, also called plant layout, consists of the production areas, production related or support areas and personnel areas within the building.

2 . Types of Layouts

Layouts can be classified as seven types: fixed position layout; process oriented layout, also called job shop; group layout; office layout; retail/service layout; warehouse layout; product-oriented layout. See fig 1.



3. Layout Design Methods and Computer Packages

It is highly desirable that the optimum plant layout be designed. Unfortunately, the magnitude of the problem is so great that true system optimization is beyond current capabilities. The approach normally taken in solving the plant layout problem is to try to find a satisfactory solution. Previously, facilities layout problems were solved primarily

by using iconic models. Then analytical approaches were developed. In general, plant layout problems can be solved by any of the following approaches:

- Exact mathematical procedures.
- Heuristics.
- Probabilistic approaches.
- Graph theory.

A number of different procedures have been developed to aid the facilities planner in designing layouts. These procedures can be classified into two main categories:

construction type and improvement type. Construction type layout methods basically involve developing a new layout from scratch. Improvement procedures generate layout alternatives based on an existing layout. Based on the above two procedures, many algorithmic approaches have been developed. Some of them are Systematic Layout Planning (SLP) procedure, steepest descent search method by pair wise exchange, graph-based construction method, programming, network, Tabu search, simulated annealing and genetic algorithm. Based on these approaches, many computer-aided layout routines have been developed. Some of them are CRAFT, CORELAP, ALDEP.

4. Computer-Aided Layout Design Software and Companies

There are two basic types of programs among computer-aided facilities planning. One is the improvement program. This kind of programs starts with a feasible solution, i.e. initial layout. They try to improve this initial layout to get a better solution. Usually quantitative flow inputs like from-to chart are used here. Examples of these programs are MULTIPLE and BLOCPLAN. Another one is the construction program. This kind of program generally develops a layout in an open area. Usually qualitative flow inputs like relationship chart are used here. Examples of these programs are SHAPE and SPS.

4.1 CRAFT

Computerized Relative Allocation of Facilities Technique (CRAFT) CRAFT is a computerized heuristic algorithm that takes in load matrix of interdepartmental flow and transaction costs with a representation of a block layout as the inputs. The block layout could either be an existing layout or; for a new facility, any arbitrary initial layout. The algorithm then computes the departmental locations and returns an estimate of the total interaction costs for the initial layout. The governing algorithm is designed to compute the impact on a cost measure for two-way or three-way swapping in the location of the facilities. For each swap, the various interaction costs are computed afresh and the load matrix and the change in cost (increase or decrease) is noted and stored in the RAM. The algorithm proceeds this way through all possible combinations of swaps accommodated by the software. The basic procedure is repeated a number of times resulting in a more efficient block layout every time till such time when no further cost reduction is possible. The final block layout is then printed out to serve as the basis for a detailed layout template of the facilities at a later stage. Since its formulation, more powerful versions of CRAFT have been developed but these too follow the same, basic heuristic routine and therefore tend to be highly CPU-intensive. The basic computational disadvantage of a CRAFT-type technique is that one always has got to start with an arbitrary initial solution. This means that there is no mathematical certainty of attaining the desired optimal solution after a given number of iterations. If the starting solution is quite close to the optimal solution by chance, then the final solution is attained only after a few iterations. However, as there is no guarantee that the starting solution will be close to the global optimum, the expected number of iterations required to arrive at the final solution tend to be quite large thereby straining computing resources. In our present paper we propose and illustrate the Modified Assignment (MASS) algorithm as an extension to the traditional CRAFT, to enable faster convergence to the optimal solution. This we propose to do by marrying CRAFT technique with the Hungarian assignment algorithm. As our proposed algorithm is semi-heuristic, it is likely to be less CPU-intensive than any traditional, purely heuristic CRAFT-type algorithm.

CRAFT uses the following procedures to improve a layout:

- Place the layout on a coordinate system.
- Determine the centroids of the departments in initial layout.
- Calculate distance matrix between departments.
- Calculate the transportation cost by multiplying the distance matrix by the from-to matrix and by the move cost matrix. significant level to make exchanges.
- Make the interchange that offers the greatest estimated reduction in transportation costs. Check all possible interchanges that have equal areas or common borders.
- Repeat until no improvement is found.

CRAFT can have the following interchanges: pair-wise interchanges; three-way interchanges; pair-wise followed by three-way interchanges; three-way followed by pair-wise interchanges; the best of pair-wise or three-way interchanges.

CRAFT can do the sensitivity analysis by using various initial layouts or by using various from-to values.

CRAFT has the following limitations:

- It cannot handle a change in material flow. It assumes the material flow is deterministic. For different material flows it creates different layouts. Each layout is only used for a specific situation.
- Number of departments is less than 40.
- Path dependence: Different initial layouts give different final solutions.

- Department shapes deteriorate rapidly with the number of iterations. Outputs contain unrealistic locations, shapes, and alignments. Manual adjustments are always required.
- The improvement algorithms cannot generally consider a negative "X" relationship.
- The improvement algorithms do not deal easily with other-than flow relationship.
- Architectural influences and other qualitative factors are very difficult to consider. They are usually ignored.
- Costs may not be significant, known, and linear in distance as assumption.

Maybe there is more than one piece of material handling equipment between two departments. In this case, there is more than one material handling cost between two departments. For example, CRAFT has only one material handling cost c_{ij} from department i to department j . The user cannot define more than one c_{ij} and cannot have different flows from department i to department j .

4.2 CORELAP

CORELAP stands for Computerized Relationship Layout Planning. It was developed by Lee and Moore in 1967. CORELAP is the oldest and best known construction routine. Its objective is to create a layout with "high-ranking" departments close together. It is a computerized version of Muther's Systematic Layout Planning (SLP). The approximations used in the relationship diagram may be more appropriate than the exact cost approach of CRAFT and COFAD because of lack of data. The assumption of CORELAP is that the department will have a dispatch area and a receiving area on the side of its layout nearest its neighbor. The input data of CORELAP are number of departments; department areas; relationship chart; and weights for relationship chart. The optional input data are scale of output printout; length to width ratio; and department pre-assignment (only along the periphery of the layout).

CORELAP uses the letter symbols A, E, I, O, U and X for the closeness relationship:

- A = Absolutely necessary
- E = Especially important
- I = Important
- O = Ordinary closeness OK
- U = Unimportant
- X = Not desirable

The letter ratings are converted to their numerical equivalents (A = 6, E = 5, etc.). The weighted relationship values (A = 35 = 243, E = 34 = 81, etc.) are used for placing departments.

Selection procedure (sequence) of CORELAP:

- Calculate the Total Closeness Rating (TCR):

$$TCR_i = \sum_{j=1}^m V_{ij}$$

where V_{ij} = Values of relationships between department i and all other departments.
($V_{ii} = 0$)

- Select the department with the highest TCR as the first one. Tie-breaking rule:
 - . department having the largest area
 - . department having the lowest department number

• Scan the relationship chart. Select the department having A with the first one. If none, then E. ... If two or more, select the one having the highest TCR. If still tied, use tie rule.

- For the third one, select the department having A with the first one. If none, select the department having A with the second one. If none, select the department having E with the first one. ...

- Repeat until all the departments are selected. Placement decision of CORELAP:
 - Locate rectangular shape departments if permitted. Length-to-width is determined by user.
 - Place the first department at the center of layout.
 - Calculate the Placing Rating (PR) for all available locations. $PR = \sum$ (weighted closeness ratings between the department to be placed and its neighbors already in layout).
 - Choose the location with the highest placing rating.
 - Tie-breaking: Take the one with the largest boundary length. Boundary length = (number of unit square sides that the department to be placed has in common with its neighbors).
- Evaluation of layout created by CORELAP:
- Calculate the layout score: Layout score = \sum all dept. (Closeness rating)*(Length of shortest path)
 - The lower, the better.
 - Path is rectilinear between departments, not between centroids as in CRAFT.
- Sensitivity analysis by CORELAP:
- Change the relationship chart.
 - Change the weighted rating values.
 - Change the departmental areas.
 - Change the layout scale (unit square).
 - Change the value of the length-to-width ratio.

Limitations of CORELAP:

- It cannot handle a change in relationship among departments. If a relationship changes, CORELAP has to create a new layout.
- The building shape may be irregular. Manual adjustment is needed.
- Shortest rectilinear path may not always be a realistic measure.

Limitations for general construction routines:

- Ignores the direction of flow among departments.
- Some important relationships are not considered.
- It is the departments instead of relationships that are considered in order of priority or importance.

4.3 ALDEP

ALDEP stands for Automated Layout Design Program. It was developed by Seehof and Evans. It is also a construction routine. ALDEP is a variation of CORELAP. Its objective is also to create a layout with "high-ranking" departments close together. But ALDEP has special characteristics of randomness, up to three floors capability and departments (docks, elevators, aisles) that can be fixed. The input data of ALDEP are length, width, and area of each floor; location and size of restricted area for each floor; scale of layout printout; number of layouts to be generated; number of departments; department areas; relationship chart; and minimum allowable score for an acceptable layout. Selection procedure (sequence) of ALDEP:

- Randomly select a department.
- Add a department with an important relationship with previous departments. If none, add an unimportant department randomly.
- Continue until all departments are added.

Placement decision of ALDEP:

- All departments are square or rectangular
- First department is put at the upper left corner
- Use "sweep" method to locate next department.

Evaluation of layout created by ALDEP:

- Check all adjacent departments. Sum the closeness values as rating value of this layout.

Limitations of ALDEP:

- It cannot handle a change in relationship among departments. If a relationship changes, ALDEP has to create new layouts.
- It ignores the direction of flow among departments.
- Some important relationships will not be considered.
- It is the departments instead of relationships that are considered in order of priority or importance.

Differences between ALDEP and CORELAP:

- By procedure: ALDEP selects the first department randomly. CORELAP selects the first department according to Total Closeness Rating.
- By philosophy: ALDEP generates many layouts and rates each layout (up to 20). CORELAP generates one best layout.

5. The MASS (Modified Assignment) algorithm

The basic idea of our proposed algorithm is to develop a systematic scheme to arrive at the initial input block layout to be fed into the CRAFT program so that the program does not have to start off from any initial (and possibly inefficient) solution. Thus, by subjecting the problem of finding an initial block layout to a mathematical scheme, we in effect reduce the purely heuristic algorithm of CRAFT to a semi-heuristic one. Our proposed MASS algorithm follows the following sequential steps:

- Step 1: We formulate the load matrix such that each entry l_{ij} represents the load carried from facility i to facility j .
- Step 2: We insert $l_{ij} = M$, where M is a large positive number, into all the vacant cells of the load matrix signifying that no inter-facility load transportation is required or possible between the i^{th} and j^{th} vacant cells.
- Step 3: We solve the problem on the lines of a standard assignment problem using the Hungarian assignment algorithm treating the load matrix as the cost matrix.
- Step 4: We draft the initial block layout trying to keep the inter-facility distance d_{ij} between the i^{th} and j^{th} assigned facilities to the minimum possible magnitude, subject to the available floor area and architectural design of the shop floor.
- Step 5: We proceed using the CRAFT program to arrive at the optimal layout by iteratively improving upon the starting solution provided by the Hungarian assignment algorithm till the overall load function $L = \sum \sum l_{ij} * d_{ij}$ subject to any particular bounds imposed on the problem. The Hungarian assignment algorithm will ensure that the initial block layout is at least very close to the global optimum if not globally optimal itself. Therefore the subsequent CRAFT procedure will converge on the global optimum much faster starting from this near-optimal initial input block layout and will be much less CPU-intensive than any traditional CRAFT-type algorithm. Thus MASS is not a stand-alone optimization tool but rather a rider on the traditional CRAFT that tries to ensure faster convergence to the optimal block layout for process-focused systems, by making the search semi-heuristic. We provide a numerical illustration of the MASS algorithm in the Appendix by designing the optimal block layout of a small, single-storied, process-focused manufacturing plant with six different facilities and a rectangular shop floor design. The model can however be extended to cover bigger plants with more number of facilities. Also the MASS approach we have advocated here can even be extended to deal with the multi-floor version of CRAFT by constructing a separate assignment table for each floor subject to any predecessor-successor relationship among the facilities.

the result from CRAFT was limited. The result of design showed only minimum total transfer cost between departments. The calculation is based on the following equations:

$$\text{Minimize } C = \sum_{i=1}^n \sum_{j=i+1}^n f_{ij} c_{ij} d_{ij} \quad (1)$$

C : Total Transfer Cost

f_{ij} : Transfer Rate From i To j

c_{ij} : Cost of Transfer From i To j

d_{ij} : Distance From i To j (From Centroid)

If the distance between departments are rectilinear, d_{ij} is calculated based on Equation (2).

$$d_{ij} = |\Delta x| + |\Delta y| \quad (2)$$

If the distance between departments are euclidean, d_{ij} is calculated based on Equation (3).

$$d_{ij} = \sqrt{(\Delta x)^2 + (\Delta y)^2} \quad (3)$$

To calculate the distance between departments, centroid of each department is calculated using equation(4) and (5).

$$X = \frac{1}{A} \int_{y_1}^{y_2} \int_{x_1}^{x_2} x dx dy = \frac{1}{2A} (x_2^2 - x_1^2) \times (y_2 - y_1) \quad (4)$$

$$Y = \frac{1}{A} \int_{x_1}^{x_2} \int_{y_1}^{y_2} y dy dx = \frac{1}{2A} (y_2^2 - y_1^2) \times (x_2 - x_1) \quad (5)$$

Based on these calculations, the result design will show only a transfer cost between departments. The good result design means less transfer cost between departments. However, there are other parameters missing such as total time in system, waiting time, or utilization.

6. Distinguishing features of CRAFT and issues relating to it are as follows:

- 1.It is a heuristic program. It uses a simple rule of thumb in making evaluations:
“Compare two departments at a time and exchange them if it reduces the total cost of the layout.” This type of rule is obviously necessary to analyze even a modest-size layout.
- 2.It does not guarantee an optimal solution.
- 3.CRAFT is biased by its starting conditions: where you start (that is, the initial layout) will determine the final layout.
- 4.Starting with a reasonably good solution is more likely to yield a lower-cost final solution, but it does not always. This means that a good strategy for using CRAFT is to generate a variety of different starting layouts to expose the program to different pair wise exchanges.
- 5.It can handle up to 40 departments and rarely exceeds 10 iterations in arriving at a solution.
- 6.CRAFT departments consist of combinations of square modules (typically representing floor areas 10 feet by 10 feet). This permits multiple departmental

configurations, but often results in strange departmental shapes that have to be modified manually to obtain a realistic layout.

7. A modified version called SPACECRAFT has been developed to handle multistory layout problems.

8. CRAFT assumes the existence of variable-path material handling equipment such as forklift trucks. Therefore, when computerized fixed-path equipment is employed, Craft's applicability is greatly reduced.

SECOND: APPLIED SIDE

****CASE STUDY IN (The General Company For Cars Industry In Hilla)**

Appendix: Numerical illustration of MASS

We consider a small, single-storied process-focused manufacturing plant with a rectangular shop floor plan having six different facilities. We mark these facilities as D1, D2, D3, D4, D5 and D6. The architectural design requires that there be an aisle of at least (2) meters width between two adjacent facilities and the total floor area of the plant is (64 meters x 22 meters). Based on the different types of jobs processed, the loads to be transported between the different facilities are supplied in the following load matrix:

	D1	D2	D3	D4	D5	D6
D1	-	20	-	-	-	25
D2	10	-	15	-	-	-
D3	-	-	-	30	-	-
D4			50			40
D5	-	-	-	-	-	10
D6	-	-	-	-	15	-

We put in a very large positive value M in each of the vacant cells of the load matrix to signify that no inter-facility transfer of load is required or is permissible for these cells:

	D1	D2	D3	D4	D5	D6
D1	M	20	M	M	M	25
D2	10	M	15	M	M	M
D3	M	M	M	30	M	M
D4	M	M	50	M	M	40
D5	M	M	M	M	M	10
D6	M	M	M	M	15	M

Next we apply the standard Hungarian assignment algorithm to obtain the initial solution: Assignment table after first iteration.

	D1	D2	D3	D4	D5	D6
D1	M-20	0	M-25	M-20	M-20	5
D2	0	M-10	0	M-10	M-10	M-10
D3	M-30	M-30	M-35	0	M-30	M-30
D4	M-40	M-40	5	M-40	M-40	0
D5	M-10	M-10	M-15	M-10	M-10	0
D6	M-15	M-15	M-20	M-15	0	M-15

There are two rows and three columns that are covered i.e. $k = 5$. But as this is a 6x6 load matrix, the above solution is sub-optimal. So we make a second iteration:

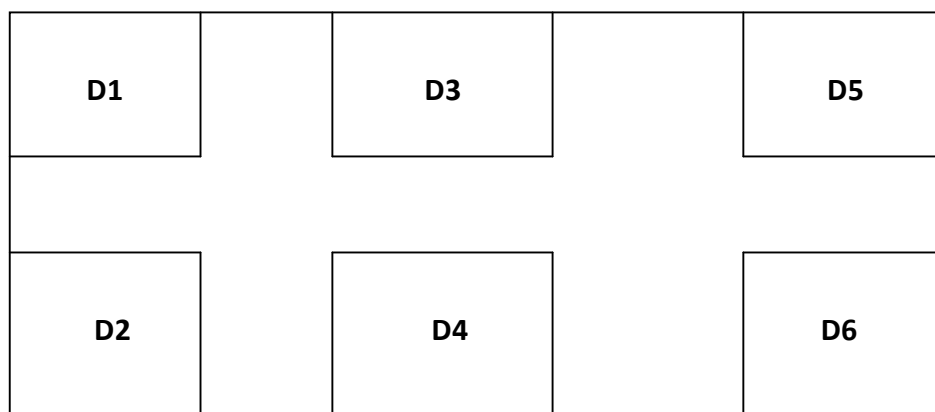
	D1	D2	D3	D4	D5	D6
D1	M-20	0	M-25	M-15	M-15	10
D2	0	M-10	0	M-5	M-5	M-5
D3	M-35	M-35	M-40	0	M-30	M-30
D4	M-45	M-45	0	M-40	M-40	0
D5	M-15	M-15	M-20	M-10	M-10	0
D6	M-20	M-20	M-25	M-15	0	M-15

Now columns D1, D3, D4, D6 and rows D1 and D6 are covered i.e. $k = 6$. As this is a 6x6 load matrix the above solution is optimal.

The optimal assignment table (subject to the 2 meters of aisle between adjacent facilities):

	D1	D2	D3	D4	D5	D6
D1	-	*	-	-	-	-
D2	*	-	-	-	-	-
D3	-	-	-	*	-	-
D4	-	-	*	-	-	-
D5	-	-	-	-	-	*
D6	-	-	-	-	*	-

Initial layout of facilities as dictated by the Hungarian assignment algorithm:



The above layout conforms to the rectangular floor plan of the plant and also places the assigned facilities adjacent to each other with an aisle of 2 meters width between them.

Thus D1 is adjacent to D2, D3 is adjacent to D4 and D5 is adjacent to D6. Based on the cost information provided in the load-matrix the total cost in terms of load-units for the above layout can be calculated as follows:

$$L = 2\{(20 + 10) + (50 + 30) + (10 + 15)\} + (44 \times 25) + (22 \times 40) + (22 \times 15) = 2580.$$

By feeding the above optimal solution into the CRAFT program the final, the global optimum is found in a single iteration. The final, optimal layout as obtained by CRAFT is as under:

D1		D6		D4
D2		D5		D3

Based on the cost information provided in the load-matrix the total cost in terms of load-units for the optimal layout can be calculated as follows:

$$L^* = 2\{(10 + 20) + (15 + 10) + (5 + 30)\} + (22 \times 25) + (44 \times 15) + (22 \times 40) = 2360.$$

Therefore the final solution is an improvement of just 220 load-units over the initial solution! This shows that this initial solution fed into CRAFT is indeed near optimal and can thus ensure a faster convergence.

Conclusions

- 1.The flexible layout design algorithm, which handles the uncertain material flow, is a heuristic improvement method. It starts with an initial layout, so the procedure is path-dependent. Different initial layouts can result in different solutions. In order to get a better solution, it is important to have a good starting point. That is why a pair exchange layout design method is used to create a layout, and its result is used as an initial layout.
- 2.This method was first used by CRAFT. It considers all possible two-way department exchanges and takes the one that gives the largest material handling cost reduction as the best exchange. The pair exchange method only picks up the best exchange at each iteration. It does not 'look back' or 'look forward' during the search. Such a solution is very likely to be only locally optimal.
- 3.The procedure used here is that from an initial layout, all possible two-way department exchanges will be considered. For each exchange, a temporary layout is built and all departments' center points are recalculated. These actual center points are used to calculate the total material handling cost. After all exchanges' total material handling costs are calculated, the exchange that has the smallest total material handling cost is the best exchange. If the smallest total material handling cost is less than the previous layout's total material handling cost, the layout is modified according to this exchange. The procedure continues until no further reduction in material handling cost can be obtained.
- 4.The method used here is a CRAFT-like algorithm, but it has some improvement. When comparing an exchange, CRAFT assumed that after two departments make the exchanges, their central points are the same as the previous departments. CRAFT used the estimated position of departments to calculate the material handling cost. If the departments differ in size, the estimated central points may deviate significantly from their correct locations. As a result, the actual reduction in the material be overestimated or underestimated. The pair exchange layout design algorithm implemented here uses the actual central points for material handling calculation, so the result is more accurate.

5. CRAFT assumed that the material flow is deterministic, so it had only one flow chart. The algorithm implemented here considers the material flow as uncertain. Users can give a distribution of the flow chart.
6. CRAFT considered only one piece of material handling equipment for the material flow between two departments. That means that there is only one unit cost between two departments. The algorithm implemented here divides the flows according to different materials. Each material can have its own material handling equipment. So users can have more than one unit cost between two departments.

Recommendations

1. In the Evaluation module, there is an assumption that the schedule of one sequence of operations doesn't affect other schedules. Capacity of departments is not considered in the Evaluation module. But in reality the departments have limited capacity. How to involve the capacity in the evaluation can be studied in the future research.
2. In this research, the building is assumed to be rectangular. While this is a required to have different dimensions. Future research could incorporate such a feature.
3. The current research assumes all material movement is between department centers. This is a very common assumption in layout approach. But in reality, receiving and shipping stations may be at the boundaries of departments. More work can be done in the future on how to handle this kind of situation.
4. The travel distances are rectilinear or Euclidean, an abstract route of material handling equipment. The material handling system is represented by material moving cost. Future research could integrate practical material handling system design into layout design. This would make the approach closer to industry application.
5. Basically, this research is a methodological approach. In a practical plant, many qualitative actors need to be considered as well as total material handling cost. Some of these are aisle arrangement, office requirements, and personnel requirements (like lockers, restrooms, food services, health services, etc.). In future studies a computer-aided drawing tool should be developed to assist the designer to modify the layout created by the algorithm.
6. Currently only one forecasting model is used. Other forecasting models can be included in this research in the future to let the users have more options in forecasting.

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