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THE FACILITY LAYOUT PROBLEM: GENERAL REVIEW

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ABSTRACT

Layout problems are found in several types of manufacturing systems. Typically, layout problems are related to the location of facilities (e.g.
Machines, departments) in a plant. They are known to greatly impact the system performance. Most of these problems are **N**on- **P**olynomial-NP hard.

Here, an attempt is made to present a general review of facility layout problems. This paper aims to deal with the theory of facility layout problems including formulations, solution approaches. Certain issues that need to be addressed while solving the layout problem are mentioned.

1. INTRODUCTION

To operate production and service systems efficiently, the systems not only have to be operated with optimal planning and operational policies, but also well designed. ***Optimal design*** of physical layout is an important issue in the early stage of the system design. The **F**acility **L**ayout **P**roblem (FLP) is the problem of designing a physical layout of ***departments*** with a certain objective such as minimizing the total material handling costs. Generally, layout design is done in two steps: design of **a block layout** and completion of **details**. In the first step, shapes and relative locations of departments are determined, while the second step specifies the location of primary equipment used in each department and incidental equipment such as gas and air lines, and lighting fixtures. Because the second step is usually quite system-dependent, **researchers** have concentrated on development of an efficient algorithm to produce a good **block layout**. **Block layout** is usually a precursor to these subsequent design steps, termed "detailed layout".

The paper is structured as follows: In Section 2 an overview of the FLP along with the definitions is described. Factors can affect facility layout problem is addressed in Section 3.Material handling costs are discussed in Section 4. Block Layout Representation concept is illustrated in section 5 since section 6 take account of modeling FLP as **Q**uadratic **A**ssignment **P**roblem (QAP). Different classification of facility layout problems are discussed in section 7.Section 8 explains the solution approaches to FLP followed by a conclusion.

2. OVERVIEW OF FACILITY LAYOUT PROBLEM

A facility layout is an arrangement of everything needed for production of goods or delivery of services. A **facility** is an entity that facilitates the performance of any job. It may be a machine tool, a work centre, a manufacturing cell, a machine shop, a department, a warehouse, etc.[1]. Due to the variety of considerations found in the articles, researchers do not agree about a common and exact definition of layout problems. The most encountered formulations are related to **static** layout problems in opposition to the **dynamic** layout problems. **Koopmans** and **Beckmann** [2] were among the first to consider this class of problems, and they defined the facility layout problem as a common industrial problem in which the objective is to configure facilities, so as to minimize the cost of transporting materials between them. **Meller**, **Narayanan**, and **Vance** [3] considered that the facility layout problem consists in finding a non-overlapping planar orthogonal arrangement of **n** rectangular facilities within a given rectangular plan site so as to minimize the distance based measure. **Azadivar** and **Wang** **[4]** defined that the facility layout problem as the determination of the relative locations for, and allocation of, the available space among a given number of facilities. **Lee** and **Lee** [5] reported that the facility layout problem consists in arranging **n** unequal-area facilities of different sizes within a given total space, which can be bounded to the length or width of site area in a way to minimize the total material handling cost and slack area cost. **Shayan** and **Chittilappilly** [6] defined the facility layout problem as an **optimization** problem(*A computational problem in which the object is to find the best of all possible solutions. More formally, find a solution in the feasible region which has the minimum (or maximum) value of the objective function*.) that tries to make layouts more efficient by taking into account various interactions between facilities and **material handling systems** while designing layouts.

Facilities can be broadly defined as buildings where people, material, and machines come together for ***stated purpose***-typically to make a tangible product or provide a service. Facility must be properly managed to achieve its stated purpose while satisfying several objectives. Such objectives include producing a product or providing a service at lower cost, at higher quality, or using the least amount of annual resources**.** **Francis etal [7]** provide a list of **objectives** that are generally considered in determining an efficient layout, including:

1. Minimize material handling time and frequency of handling.
2. Minimize capital and operating cost in equipment and plant.
3. Increase effective and economical use of space.
4. Facilitate the manufacturing process and flow of operation.
5. Maintain flexibility of arrangement and operation.
6. Provide for safe and efficient construction.

3. SOME FACTORS THAT CAN AFFECT THE FACILITY LAYOUT

Tompkins et al. **[8]** mention some of the material handling decisions that affect the layout of a facility, and the major ones are: material handling equipment, material handling path, and handling unit size (unit load size). The material handling equipment and the material-handling path are not mutually exclusive. For instance, conveyors are material handling equipment used in a manufacturing plant to move the materials between specific points, such that the material-handling path is fixed. On the other hand, material handling equipment like forklifts, trucks and Automated Guided Vehicles (AGVs) are used to transport materials between various points, whereas the material-handling path is not fixed. Therefore, the decision of determining what type of material handling system (equipment) should be used has a significant impact on the effectiveness and flexibility of the facility layout. For instance, using forklifts in a flow shop is not economical since the volume of workflow between the machines is very high. Therefore, using forklifts can increase both work in process inventory and material flow congestion.

Another factor, which affects the layout, is the unit load. The number of units handled at a time is called the unit load. By handling batches of material at a time, it reduces the number of trips needed to transfer the material, material handling costs, and damage to the material while transferring. Containers, pallets, tote boxes, and cartons are some of the unit load containers used in industry. The size and weight of the unit load containers can influence and be influenced by the material handling equipment, which in turn influences and is influenced by the layout. For example, a forklift cannot be used to lift a container which is heavier than its lifting capacity. Also, a roller conveyor cannot be used to transfer a tote box which is dimensionally incompatible. Thus, the unit load size is closely related to the material handling equipment being used, which is in turn associated with the facility layout.

Apart from the material handling decisions, there are some other factors that can also affect the layout, and they are as follows: change in the product design, the addition or deletion of a product, changes in the production methods, replacing obsolete equipment, and the adoption of new safety standards. A change in the product design calls for changes in the processes or operations to be performed. This change may require minor alterations in the existing layout or it may result in an extensive re-layout. When a new product is added, which is not considerably different from those in production, it may require minor alterations of the existing layout. Otherwise, new machines may be brought in for production, and the layout has to be changed in order to accommodate the new machines. This is also the case when there are changes in the production methods.

When deleting a product, the material flow between departments (machines) may decrease. This reduction in the flow requires the layout planner to re-evaluate the layout. The evaluation may or may not result in changing the existing layout. In the case of obsolete equipment, additional space may be required to move the equipment. After removing the equipment more space may be available, and the layout may be altered to use this additional space. The extent of the layout alteration depends on the number of machines moved and their sizes. Last, when new safety standards are adopted, it may increase the space available for worker movement. The increased space requirement may burden the layout, and it may lead to changing the existing layout.

Gradual changes over time display themselves in terms of production bottlenecks, material flow congestion, failure to meet schedules, unexplainable delays, and increased idle time. Furthermore, over a period of time, demand changes. When the changes are left unattended, this may cause either a burden on the machinery and workforce needed to meet demand or to operate efficiently or under utilization of both machinery and workforce. In the former case, increased material flow increases space required to move the material; thus, causing flow congestion on the shop floor and burdening the capacity of the material handling equipment. In the latter case, reduced material flow reduces the utilization of the material handling equipment, machinery and workforce. it may result in under-utilization of resources. Therefore, the existing layout should be re-evaluated.

4. MATERIAL HANDLING COSTS

Material handling cost is the most significant measure for determining the efficiency of a layout and is most often considered, since it represents 20 to 50% of the total operating cost and 15 to 70% of the total cost of manufacturing a product. **[8].**

Material handling costs are approximated with one or more of the following parameters: **interdepartmental flows**, **v ij** (the flow volume measured in trips per unit time from department i to department j); **unit-cost values**, C_{ij} (the cost to move one unit load one distance unit from department **i** to department **j**, including cost of material handling equipment, labor cost, and inventory cost for time in transit); and the **department closeness ratings**, **r ij** (the numerical value of a closeness rating between departments **i** and **j**). Alternatively, these parameters can be used as subjective weights including safety, customer importance, and other factors as well as standard accounting costs. If all movement is of equal concern, all **C ij** may be set to **1**. These parameters are used in two common surrogate material handling cost functions. **[7]**. The first of the two surrogate material handling functions is based on departmental adjacencies:

$$\max \sum_{i} \sum_{j} (r_{ij})(x_{ij}) \quad (1)$$

where **x ij** equals 1 if departments i and j are adjacent, and 0 otherwise. Such an objective is based on the material handling principle that material handling costs are reduced significantly when two departments are adjacent.

The second of the two surrogate material handling cost functions is based on interdepartmental distances:

$$\min \sum_{i} \sum_{j} (v_{ij})(c_{ij})\ (d_{ij}) \quad (2)$$

$$\min \sum_{i} \sum_{j} (v_{ij})(c_{ij})\ (d_{ij}) \quad (3)$$

Where **d ij** is the distance from department **i** to department **j**. This objective is based on the material handling principle that material handling costs increase with the distance the unit load must travel. The distance is primarily measured in one of two ways. The most accurate distance measure is the distance between input/output (I/O) points. This distance is measured between the specified I/O points of two departments and in some cases is measured along the aisles when traveling between two departments. The major drawback of this accurate measure is that one does not know the location of the I/O points (or aisles) until one has developed *a detailed layout***.** The input and output points of the departments are typically unknown.

Consequently, the **department centroid** is widely used to approximate the department I/O point. Geometrically, the **centroid** can be defined as the center of gravity or center of mass of an object. In the facility layout domain, the centroid of a department is the center of the department, and it represents both the I/O points. .One of the shortcomings of centroid-to-centroid (CTC) distances is that the optimal layout is one with concentric rectangles , For each of the aforementioned distance measures, there are two metrics used to measure the distance between two points. **Rectilinear distance** (*appropriate for automated guided vehicles and forklift trucks*) is most commonly used metric because it is based on travel along paths parallel to a set of perpendicular (orthogonal) axes. The second metric, **Euclidean distance** (*appropriate for conveyor lines*), is appropriate when distances are measured along a straight-line path connecting two points. If there is a large amount of volume flow between two departments, then the departments should logically be assigned locations so that they are near each other to minimize transportation and handling costs. **Rectilinear** distance between any two points (x1, y1) and (x2, y2) is given by |x1-x2|+|y1-y2|, and ***Euclidean*** distance between two points is defined by SQR $(x1 - x2)^2 + (y1 - y2)^2$. **[9].**

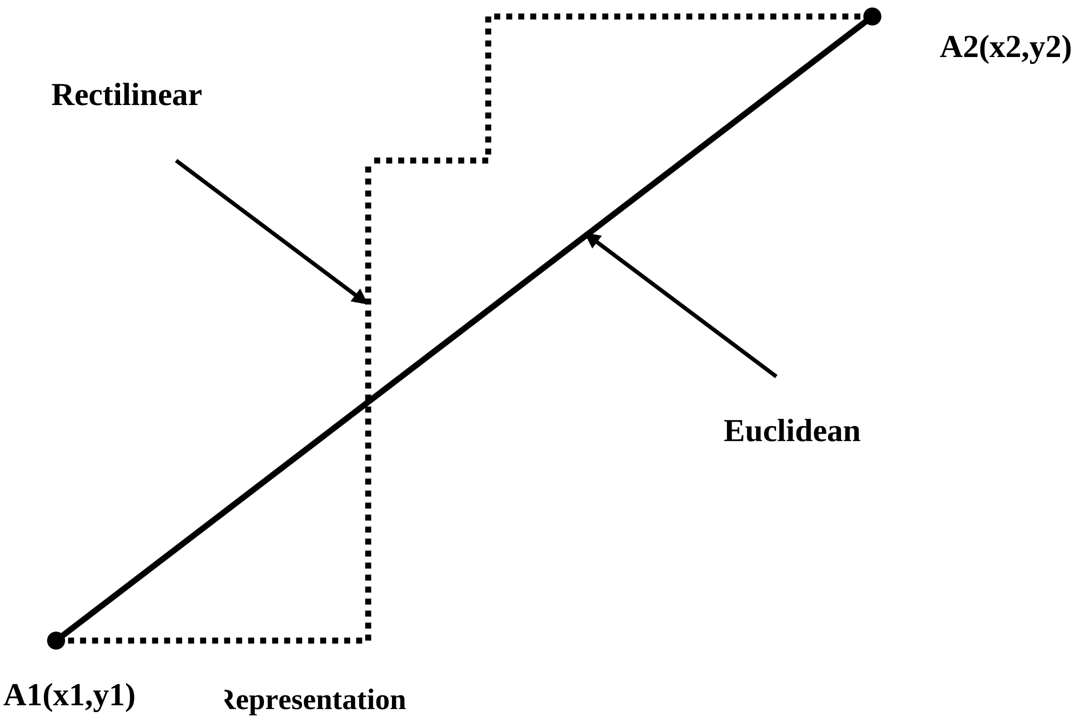

Figure (1): Rectilinear vs. Euclidean Distance.

A typical approach to the facility layout problem is to combine tasks or equipment into functional groups, or blocks. Once knowledge of the materials flow, process details, and support activities is known, it is possible to locate different **blocks** on the layout based on their relationships with each other. Specifying the relative location and size of
each department within a facility, this common representation of solutions to the facility layout problem is referred to as the block layout **.**

Block layouts are used to provide preliminary information to architects and engineers involved in the construction of a new facility. The block layout is typically represented in either a **discrete** or **continuous** fashion. A **discrete** representation of the block layout uses a collection of **grids** to
represent departments . However, a continuous representation uses the centroid, area, perimeter, width and/or length of a department to specify the exact location of the department within a facility layout. In the literature, most of the facility layout algorithms use a discrete representation to generate the block layout. **[10].**

6. THE QUADRATIC ASSIGNMENT PROBLEM (QAP)

The facility layout problem was first modeled as a Quadratic Assignment Problem (QAP) by **Koopmans** and **Beckmann** [2]. The QAP formulation assigns each department to exactly one location and exactly one department to each location. The cost of assigning a department a particular location is dependent on the location of interacting departments. This dependency leads to the quadratic objective that inspires the problem's name.

The Quadratic Assignment Problem (QAP) can be conveniently defined when we introduce two sets, **R** and **T**. Each of the sets contains N elements, indexed from

1 to N. The problem is to assign every element of **R** to exactly one element of **T** in order to achieve some objective. The QAP can be formulated as a binary program with a second-degree polynomial objective function and linear constraints:

$$\min \quad Z(x) = \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1}^{N} \sum_{l=1}^{N} C_{ijkl}\, x_{ij}\, x_{kl} \quad (3)$$

$$S.T \sum_{j=1}^{N} x_{ij} = 1 \; i = 1,2,.......N \; (4)$$

$$\sum_{i=1}^{N} x_{ij} = 1 \;\; j = 1,2,.......N \;\; (5)$$

$$x_{ij} \varepsilon \{0,1\} \; i, j = 1,2,........N \; (6)$$

The binary decision variables xij are 1 if element i ε R is assigned to element j ε T and 0 otherwise. The constraints ensure that the assignment
is feasible. To determine the cost of an assignment the coefficients C_{ijkl} are to be used. They represent the cost of assigning i ε R to j ε T and, simultaneously, k ε R to L ε T.
The QAP has a large number of applications in science and engineering. One well-known example is the problem of locating ***plants*** with material flow between them to minimize material transportation cost. considering **R** to be the set of plants, and **T** to be the set of locations. The cost of locating the plants only depend on the amount of material shipped (**b_{ik}**)
and the distance between the plants (**d_{jl}**), then it is possible to replace the coefficients **C_{ijkl}** by: **$C_{ijkl} = b_{ik}\, d_{jl}$** .
Other applications include the layout of electronic components on a printed circuit board, scheduling jobs on a multiple-processor computer
and the design of keyboards .

7. CLASSIFICATION OF FACILITY LAYOUT PROBLEMS

The flow data used for determining the layout classifies the layout problem into two categories: **static** and **dynamic**. If the flow data between the departments does not change over time, then the problem is defined as the **S**tatic **F**acility **L**ayout **P**roblem (**SFLP**). When the flow changes over time, then the problem is defined as the **D**ynamic **F**acility **L**ayout **P**roblem (**DFLP**). **Rosenblatt** (**1986**) was the first to define the **DFLP**. Furthermore, the nature of the flow data can be characterized as **deterministic** or **probabilistic**. Deterministic flow data is fixed and known with certainty. That is, during the planning horizon, material flow between the departments is known with certainty. When the flow data are not known with certainty, they can be represented as random variables. That is, the behavior of the flow data can be approximated by a probability distribution. In other words, the flow data are said to be probabilistic. **Kouvelis et al** [11] addressed the probabilistic nature of the flow data for the facility layout problem.

8. Solution approaches

Although the QAP is relatively easy to formulate, it is very difficult to solve. QAP is **N**on- **P**olynomial (NP-hard), and only implicit enumeration methods are known for solving it optimally. These approaches are based on branch-and-bound, **Gavett, J.W., and Plyter, N.V[12]** or cutting plane methods, **Bazaraa, M.S., and Sherali, M.D [13]** .However, empirical studies suggest that the general QAP is too difficult to be solved optimally. branch-and-bound algorithm ran 18 hours on a 32-node Intel IPSC/2 hypercube to solve a problem of size N = 18 , **[14].**

Since most real-world problems are of size N > 18, **heuristics** are used to find "good" solutions within reasonable time. In order to obtain good (near optimal) solutions in a reasonable amount of time, heuristic algorithms were developed. A heuristic can be defined as a well-defined set of steps for quickly identifying good quality solutions. The quality of a solution is defined by an evaluation criterion (e.g., minimize material handling cost), and the solution must satisfy the problem constraints. **Heuristics** for the QAP can be classified as **construction**, **improvement** or **global-search heuristics**.

Construction heuristics begin with the basic problem data and build up a solution in an iterative fashion. Initially, all elements of **R** and **T** are unassigned. Empirical studies have shown that construction heuristics generate solutions of poor quality .

Improvement heuristics and global search heuristics on the other hand, start with an initial feasible solution and try to improve it. The most common improvement heuristics for the QAP are **pairwise exchange** improvement heuristics. They select two elements of **R** and compute the change in the objective function value when their counterparts in **T** are exchanged. The exchange is only realized when it improves the objective function value. This procedure is repeated until no further improvements can be found. The major disadvantage of improvement Heuristics is that they usually get **stuck** in **local optima** and hence produce sub-optimal solutions.

Global-search heuristics try to escape these local optima by occasionally accepting exchanges that increase the objective function value. The best-known global-search heuristics are **Tabu Search**, **Genetic algorithms** and **Simulated Annealing.**

Conclusion

In this paper, a recent comprehensive survey related to facility layout problems is presented. Although this survey cannot be exhaustive, the analysis carried out is based on a number of literature references. From this analysis, it appears that articles related to layout design continue to be regularly published in major research journals and that facility layout remains an open research issue.

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