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Dynamic Facility Layout Problems: A Survey

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ABSTRACT

The facility layout planning plays very important role in the manufacturing process and seriously impacts a company's profitability. An effective layout may minimize the material flows and distances between the department locations which lead to the reduction of material handling costs often improvement in cycle time. To keep up with the pace, the facility layout needs to be adaptable to changes. The layout has to be "flexible" enough to accommodate changes in product design, process design and schedule design [1]. Optimizing facilities layout in a manufacturing plant is basically to arrange the machines in the workshop area with the best sequence to increase the performance of the factory. Researchers have found out that it is possible to reduce the manufacturing costs up to 30% by an effective arrangement of machines or departments because it was estimated that 20 to 50% of the costs are due to the handling of material or work pieces. Therefore looking into such high percentage of return, many researches had done to provide the "best layout" to the facility layout problem [2].

It is necessary to redesign the facility layout for improvement in production processes that will accept the future changes coming in manufacturing, smooth operating and makes the profit to run the business. So forecasting and readiness has got the prime importance. This paper mainly discusses about Dynamic Facility Layout Problems (DFLP) and methods to solve the DFLP.

KEYWORDS – Static facility layout problem, Dynamic facility layout problem, Quadratic assignment problem

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1. INTRODUCTION

A facility layout is an arrangement of everything required for the production or delivery of services. It is an entity that facilitates the performance of any job. It may be a machine tool, a manufacturing cell, a machine shop, a department, a warehouse etc [3]. The most important parameter which is responsible for the changing environment is volatility. Under a volatile environment demand is not stable. It changes from one production period to another. To operate efficiently under such environment, such facility must be adaptive to changing production requirements. From a layout point of view this situation requires the solution of DFLP. DFLP is computationally complex combinational optimization problem [4]. The problem of arranging and rearranging the layouts of facilities for multiple time periods during a planning horizon (i.e., when the material flow between the departments changes) is called as Dynamic facility layout problem [5].

A plant layout must designed in such a way that it should be flexible enough to respond the changes may occur once set up of machines or departments is done. Considering these problems at the time of plant layout designing to maintain the plant layout effectiveness is DFLP.

2. WORKSHOP CHARACTERISTICS IMPACTING THE LAYOUT

Layout problems are strongly dependent on the specific features of the manufacturing systems are as follows,

1. Production variety and volume
2. Facility shapes and dimensions
3. Material handling system
4. Multi-floor layout

5. Backtracking and bypassing
6. Pick up and drop off locations [3].

2.1 Types of Facility Layout Problems

The analysts divide a facility into practical divisions called departments and calculate the quantity of material flowing between pairs of departments. Classification of facility layout problems as follows,

1. Job shop layout
2. Cellular manufacturing layout
3. Product layout
4. Office layout
5. Store layout
6. Warehouse layout [5]

2.2 Job shop layout

The facility layout problem under Job shop layout is classified in two categories,

1. Static Facility Layout Problem
2. Dynamic Facility Layout Problem

2.3 Difference in Static and Dynamic Facility Layout Problems

The manufacturing plants must be able to respond quickly to changes in demand, production volume and product mix. However, the change in product mix yields to modify the production flow and thus affects layout. Most articles dealing with layout problems are implicitly considered as static; in other words they assume that the key data about the workshop and what it is intended to produce will remain constant enough over a long period of time. Dynamic layout problems take into account possible changes in the material handling flow over multiple periods. In this respect, the planning horizon is generally divided into periods that may be defined in weeks, months or years. For each period, the estimated flow data remains constant. A layout plan for the dynamic layout problem consists of series of layout, each layout being associated with a period.

1	2	3
4	5	6
Period 1		

2	1	5
3	6	4
Period 2		

3	5	6
1	4	2
Period 3		

6	4	1
2	5	3
Period 4		

Figure 1: Evolution of layouts over four periods

Figure 1 shows a layout with six equal size locations to be arranged in each of the four periods in the planning horizon. The objective can be to determine a layout for each period in the planning horizon, while minimizing the sum of the material handling costs, for all periods, and the sum of the rearrangement costs, for all periods [3].

3. SOLUTION TO LAYOUT PROBLEMS

3.1. Formulation of layout problems

1. Discrete formulation
2. Continual formulation
3. Fuzzy formulation
4. Multi-objective layout problems

Discrete formulation

Discrete representation of the layout is commonly used for dynamic layout problems. The problems addressed are related to equal size facilities addressed as QAP.

Continual formulation

It is also called as Mixed Integer Programming Problems. All the facilities are placed anywhere within the planar site and must not overlap each other.

Fuzzy formulation

The data affecting layout problems are not exactly known in some cases. In such cases Fuzzy logic has been proposed to handle the uncertainty that is often encountered. Unequal size facilities problem on the plant area can be solved by Fuzzy approaches.

Multi-objective layout problems

The main objective is to minimize a function related to the travel of parts (MHC, travel time, travel distance). To be more realistic, some researchers have considered more than a single objective. For example, minimizing material handling flow, equipment flow and the information flow. It leads to use of AHP methodology, Pareto approach.

3.2 Resolution approaches

1. Exact approaches (for small size problems)
2. Approximated approaches (for large size problems)

Exact approaches

Branch & Bound, Dynamic programming and Cutting plane are effective for equal size and rectangular facilities but effective only for small problem instances.

Approximated approaches

1. Construction approaches – CORELAP, ALDEP, COFAD, SHAPE, CRAFT, DISCON
2. Global search methods – Tabu search, Simulated annealing
3. Evolutionary approaches – Genetic algorithm, Ant colony optimization [3].
4.

4. SFLP

For the Static Facility Layout Problem (SFLP) it is assumed that the flow of material between the departments does not change during the planning horizon, based on the final layout design a particular layout is executed and remains unchanged for the lifetime of the layout. The flow of the materials is deterministic and constant over the entire time planning horizon.

4.1 Methods used to solve SFLP

A large number of procedures have been developed to solve the SFLP. These procedures can be classified into two main categories: construction type and improvement type. Basically, construction type layout methods involve developing a new layout from scratch. Improvement procedures generate layout alternatives based on existing layout. Solution methods for both types of problems have been developed and these can be classified into three major groups,

1. Mathematical approaches
2. Heuristic methods
3. Expert system solutions

The mathematical approaches can be summarized under the following four categories:

1. Linear integer programming
2. Mixed integer programming
3. Quadratic assignment
4. Quadratic set covering

The typical heuristic methods used to solve the SFLP are as follows,

1. Ant Colony
2. Pair wise exchange
3. Tabu search
4. Simulated Annealing
5. Artificial neural networks
6. Genetic Algorithm

4.2 Drawbacks of SFLP

In today's manufacturing environment, products change frequently, and it is not possible to correctly predict this change for long time periods. Therefore, there are several major factors which may impact the layout of a facility and some of them are: applying a new technology to existing products, changing the volume of a product, or adding or deleting some new products, etc. Any of these changes usually results in redesigning the layout, since the current layout usually gives high material handling cost.

5. DFLP

For the DFLP it is assumed that the flow of the material between the departments changes during planning horizon. For constantly changing attributes in the manufacturing system, there is need to consider a flexible layout, which can handle future scenarios. Generally changes in the flow are the result of many factors such as,

1. Changes in the production quantities and associated production schedule.
2. The change in the design of an existing product.
3. The elimination of the product from a product line.
4. The introduction of new products.
5. Replacement of existing production equipments.

DFLP assumes that material flow can be predicted accurately. If the future material flows and departments rearrangement cost can be reasonably estimated then this problem is dynamic and can be solved by modeling the problem as a DFLP. Initially this problem was solved as SFLP, for each time period in the planning horizon. The DFLP is the problem of efficiently arranging the departments within a facility during a multi-period planning horizon such that the sum of material handling cost is minimized [5].

5.1 Models used for DFLP

1. Rosenblatt in 1986 proposed a model of dynamic layout. It was first paper to be published on DFLP. He proposed a dynamic programming model.
2. Lacksonen and Enscore used branch and bound algorithm, cutting plane algorithm, cut trees and CRAFT.
3. Urban proposed a steep-descent pair-wise interchange procedure combined with the concept of forecast windows.
4. Balkrishnan, Cheng and Conway proposed an improvement to Urban's forecast windows procedure for solving the DFLP by complementing it with the backward method.

5. McKendall and Jin Shang proposed three variants of Ant Colony Optimization models for solving the DFLP. HAS-I is derived from Gambardella's HAS-QAP with adaptation for DFLP. HAS-II combines the ideas of HAS-I and SA. HAS-III adds the look ahead/ look back strategy to the PE (local search) [1].

5.2 Methods used to solve DFLP

Most of the formulations of the DFLP are extensions of the QAP used for the SFLP. There are several algorithms used to solve the DFLP. The most common heuristic methods used to solve the DFLPs are,

1. Pair wise exchange
2. Cutting plane
3. Branch and bound techniques
4. Cutting trees
5. Genetic Algorithms
6. Tabu search
7. Ant Colony Optimization
8. Simulated annealing

Pair-wise exchange

It is a random descent heuristic, which is repeated for a certain number of iterations and used to improve the initial set of solutions and the set of modified solutions. Randomly two departments are selected and exchanged.

Cutting Plane

This algorithm adds a constraint to the model to cut off the continuous regions. The FLP formulated by QAP with maximum 25 facilities can be solved optimally by cutting plane algorithms. It is found that the cutting plane algorithm has the best performance in comparison with computerized relative allocation of facilities technique (CRAFT), B&B and DP algorithms for solving the DFLP modeled by the QAP.

Branch & Bound

Branch and bound (B & B) solves a problem in such a way that at each iteration, the current problem is branched into smaller sub-problems. The branches with non-improving solution or infeasible solution are pruned. Finally, when all branches have been pruned, the optimal solution (if any) is found. This method can be used to solve the small sized FLPs (up to 16 facilities) formulated by the QAP in a reasonable computational time.

Genetic Algorithm

GA starts with a population of randomly generated initial solutions named chromosomes. Each chromosome consists of genes, which are usually represented by binary digits. The initial population evolves through successive iterations into an optimal solution. Each iteration (generation) of this algorithm is formed by four stages, including selection, evaluation, crossover and mutation. Using the selection procedure, a group of individuals (chromosomes) from the current population are selected at random as parents to generate the children (offspring) for the next generation. Using the evaluation procedure, the chromosomes are evaluated by using their objective function (fitness) values. The chromosomes with higher fitness value have higher likelihood to be selected. Finally, the best chromosome (solution) is obtained after several iterations.

Tabu Search

Tabu search starts with an initial solution s^0 as the best current solution s (i.e. $s^0 = s = s^1$). At each iteration, a new solution s′ is produced during a local search process in the neighbourhood of the current solution s. If the solution s′ is better than the current solution s, then, it is considered as the best current solution (i.e. $s^0 = s = s^1$). In order to find the optimal solution s*, the just found solutions, which are 'taboo' and forbidden to be visited, are stored in a 'tabu list', including long-term and short term flexible memories. The number of these taboo solutions is named the memory (tabu list) size. For keeping the size of the tabu list constant, the oldest member must be removed from the list. The above-mentioned instructions are repeated until termination criterion is fulfilled.

Ant Colony Optimization

ACO algorithm takes inspiration from the social behavior of real ants to find the shortest path from the nest to the food source. As the ant moves along a randomly selected path, it lays a volatile value of a chemical substance named pheromone on the path. Using the smell of the pheromone as an indirect communication named stigmergy, the other ants follow the path and thereby, the amount of pheromone on the path is increased. Finally, the ants find the shortest path from the nest to the food source.

Simulated annealing

Metropolis et al. suggested a useful technique to simulate the thermal motion of atoms during a cooling process. Kirkpatrick, et al. proposed the first SA algorithm by generalizing the metropolis's approach and replacing the atom's energy with the cost function [5].

6. REVIEW OF DFLP

Gary Chen and Jamie Rogers, while describing DFLP, determined the time dimension as important factor into the facility layout planning. To construct a DFLP the facility planners must take the time periods, discrete time intervals where the material flows and facilities rearrangement occur in the planning horizon into account. At each time period the material flow costs and rearrangement costs need to be considered and evaluated to deem if the facility rearrangement is necessary. They combined quantitative based objectives with qualitative based objectives to make a Dynamic multi-objective facility layout [6].

Ghorbanali Moslemipour et al. explained that dynamic layouts are flexible enough to cope with fluctuations and uncertainties in product demands and volatile environment of flexible manufacturing system. Since, the DFLP is a hard combinatorial optimization problem, intelligent approaches are most appropriate methods for solving the large size of the problems in reasonable computational time [7].

Alan R. McKendall Jr. and Jin Shang proposed that manufacturers must be competitive in today's consumer market. This requires efficient operation of manufacturing plants and their ability to quickly respond to changes in product mix and demand. Material handling cost make up between 20 and 50 percent of the total operating cost. Therefore they considered the problem of arranging and rearranging, when there are changes in product mix and demand, manufacturing facilities such that the sum of the material handling and rearrangement costs is minimized. This problem is called dynamic facility layout problem (DFLP). They developed hybrid ant systems to solve DFLP [8].

Adil Baykasoglu et al. explained that one of the characteristic of today's manufacturing environments is volatility. Under a volatile environment (or dynamic manufacturing environment) demand is not stable. To operate efficiently under such environments facilities must be adaptive to changing demand conditions. This requires solution of the dynamic facility layout problem (DFLP). DFLP is a complex combinatorial optimization problem for which optimal solutions can be found for small size problems. Their research makes use of a simulated annealing algorithm to solve the DFLP [9].

Jaydeep Balkrishnan et al. stated that the design of facility layouts is based on a multi-period planning horizon. During this horizon, the material handling flows between the different departments in the layout may change. This necessitates a more sophisticated approach than the SFLP approach. The DFLP extends the SFLP by assuming that the material handling flows can change over time. This in turn might necessitate layout rearrangement during the planning horizon. In an environment where flows do not change over a long period of time, the SPLP is justified. But in today's market based and dynamic environment, such flows can change quickly. On an average, 40% of a company's sales come from new products. In the dynamic environment, static approach can be used in two ways. The first is to use a short planning horizon so that during this horizon the flows are fairly constant. The disadvantage is that after the short horizon, if the relative flows change, the layout will have to be rearranged ad hoc. Otherwise the result will be an inefficient layout. Rearranging layouts frequently without prior planning can result in operational disruptions and excess rearrangement costs. The second approach is to use a long planning horizon and disregard the changes in flow. There will be no rearrangement costs, but this may result in the layout being inefficient throughout the horizon. The dynamic approach to layout corrects the above deficiency. In the dynamic approach, layouts are planned based on a multi-period time horizon [10].

7. CONCLUSION

In this paper DFLP discussed is considered to deal with volatile environments. The DFLP approach has the advantage of having optimal layout for each period, but it suffers from the disadvantage of having the facility rearrangement cost. Looking towards changing customer's requirements and business competition the manufacturer must be able to withstand the changing environment. Therefore from business point of view manufacturing must be flexible enough to accommodate the changes coming in customer's orders, design of the products, addition or deletion of the product, obsolescence of the equipment etc. the plant must respond quickly to the changes expected in manufacturing. The time taken to respond the changes will lead to the loss in production so as the profit of the company. The planning and designing of the plant layout must consider all the factors responsible for the Material handling cost. DFLP considers all the factors affecting on layout, time periods and rearrangement costs while designing the layout, proved effective than SFLP.

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