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STRATEGIC LAYOUT PLANNING AND SIMULATION FOR LEAN MANUFACTURING A LAYOPT™ TUTORIAL

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ABSTRACT

LayOPT™ is an innovative facilities layout analysis and optimization software package which can be used by layout planners and engineers in the optimal solution of single and multiple floor facility layout problems. LayOPT is ideal for the re-design of the overall layout for an existing facility or the development of a block layout for a new building. It can be applied to manufacturing, warehouse, office, and various service facility layout problems. This tutorial describes the LayOPT methodology and presents an overview of the software's features and capabilities.

1 INTRODUCTION TO LAYOPT

LayOPT is a facilities layout optimization software package which can be used by layout planners and engineers to solve single and multiple floor facility layout problems. It can be applied to manufacturing, warehouse, office, and various service facility layout problems. LayOPT allows the layout planner to generate alternative layout plans quickly and easily and to find the optimal layout among these alternatives.

LayOPT is an improvement algorithm that starts with an existing block layout, and given the flow and cost data, attempts to improve it by exchanging the locations of defined departments. While several available improvement algorithms perform basically the same function, many are severely limited by the kinds of exchanges they could perform. Not uncommon among them are constraints either on the layout itself or on the type of exchanges that could be considered (for instance, only equal area or adjacent departments). Consequently, results obtained from these algorithms may lead to inferior solutions. LayOPT overcomes these limitations and generates solutions that are generally 50% to 80% more efficient than their starting points.

LayOPT is a Windows-based software system with all the amenities of a user-friendly interface, including pull-down menus, toolbars, status bars, user-defined window sizes, and an on-line help system. It comes with a User's Guide/Reference and a Training Manual.

1.1 The LayOPT Algorithm

LayOPT is an improvement algorithm for developing alternative and efficient block layouts from an initial block layout provided by the user. The initial layout is typically either the existing or a proposed layout. In the absence of an initial layout, one may also be randomly generated by the program. The seed algorithm used in LayOPT is based on the algorithm developed by Bozer, Meller, and Erlebacher (1994).

LayOPT's algorithm is a steepest-descent, two-way exchange optimization routine. In each iteration, the algorithm picks the department pair whose exchange leads to the largest reduction in the objective function. It then automatically exchanges the pair to proceed to the next iteration. The objective function minimized by the LayOPT algorithm is the sum of the parts flows multiplied by the appropriate costs and expected distances between all department pairs with non-zero parts flow between them.

1.2 LayOPT Terminology

Before we describe the steps in creating and analyzing a layout problem in LayOPT, a brief discussion of commonly used terms is presented below.

1.2.1 Building and Grids

The building is the actual physical facility whose layout is being determined. It may consist of a single floor or more than one floor, including partial floors (mezzanines or loft areas with limited vertical access). The building footprint defines the actual shape (rectangular or irregular) of the building when viewed from the top. To represent a non-rectangularly shaped building in LayOPT, the smallest enclosing rectangle is drawn to surround the building footprint. As in most computer-based layout algorithms, layouts in LayOPT are represented as a matrix. Each element of the matrix corresponds to a grid square (or simply, grid) of specified area.

1.2.2 Floors and Lifts

A floor in LayOPT corresponds to a floor level in a facility. It may either be an actual floor or a mezzanine. Lifts are vertical material handling devices that allow for the transport of materials and people from one floor to another in a multi-floor facility. These may include elevators, vertical reciprocating conveyors (VRCs), gravity chutes, etc.

1.2.3 Departments

Departments are the smallest planning units that comprise a facility. A *department* may be an actual process department, a product cell, a single machine, a group of machines, or any part of the facility (offices, cafeteria, rest rooms, shipping and receiving docks, etc.) whose location relative to other departments is being determined.

A fixed department is one whose location is designated in the initial layout and is not allowed to change during optimization. Fixed departments are not considered when evaluating pairwise departmental exchanges. A free department is one whose location is allowed to change during optimization. All free departments are considered when evaluating pairwise departmental exchanges.

1.2.4 Obstacles

An obstacle is a general term used to describe any unusable part of a facility. Such obstacles include building columns, safety areas, freight elevators, etc. Obstacles may also be used to depict non-existing building areas as when representing a non-rectangularly shaped building with an enclosing rectangle, or when representing a mezzanine with an entire floor.

1.2.5 The Space Filling Curve

The space filling curve (SFC) is a device entered by the user and used by LayOPT to construct the layout. The SFC is a continuous line that visits all the assignable grids in a particular floor in the facility. To construct the layout, a set of departments whose areas fit in the floor defined by the SFC is sequenced along that curve. An SFC guarantees that no department is split because a separate curve is used for each floor and, within each floor, the curve visits the *neighbors* of a grid before visiting other grids.

Space filling curves can be drawn through virtually any building with obstacles and fixed departments as long as an obstacle or fixed department does not split the building into two or more disjointed pieces.

1.2.6 Flows and Weight Factors

Flow represents parts, information, or people that are transported from one department to another. These may be in the forms of actual part pieces, pallets, boxes, racks, bins, etc. The From-To chart is a table containing flow values from one department to another in a form similar to a mileage chart.

Weight factors represent either the actual unit costs associated with the individual flow values in the From-To chart or simply relative weights. Relative weights (on a user-defined scale) may represent such intangible factors as difficulty of the material moves, environmental and safety issues on various parts flows, or preferences for specific material handling containers. LayOPT minimizes either the layout cost expressed in dollars per unit time or the overall weighted sum of parts travel in the facility.

1.2.7 Layout Assessment

Layout assessment is the value of the objective function calculated by LayOPT : the sum of the flows multiplied by the appropriate weights and expected distances between all department pairs with non-zero parts flow between them. A lower layout assessment generally means a better layout.

2 METHODOLOGY

Creating a project in LayOPT involves defining the basic input data required to describe an initial layout and execute an optimization run, namely: (a) the building or facility, (b) departments and departmental properties, (c) flow and cost values, and (d) an initial departmental block arrangement.

2.1 Defining the Building

LayOPT can capture virtually any building shape and size. The grid size used in the matrix representation of the building shape is entirely dependent on the needs of the user. In general, a finer grid size can more accurately represent departmental areas and shapes, though, at the expense of faster computational run times. The opposite is true for a larger grid size -- less precision but faster run times. Depending on the grid size selected by the user, LayOPT can represent a department or an obstacle 5 ft. by 5 ft. in size, or even smaller.

Multi-level facilities are easily represented by assigning multiple floors to the building. In this regard, floor separation heights may or may not be the same across all floors. Vertical material handling equipment to transport parts, people, or products to and from departments on different floors can be placed anywhere on a floor and are assumed to service all defined floors. LayOPT concurrently optimizes the layouts of all the floors, i.e., each floor's layout is not developed independently of the others.

2.2 Defining Departments

A department is uniquely identified by its number and description. Defining a department also includes specifying its area requirements in square distance units (sq. ft. or sq. meters) or grids and designating it as free or fixed. Additionally, floor restrictions may be defined -- floors where the department may not be located at any time during and after the optimization run.

LayOPT does not limit department shapes to rectangles or squares. Departments can assume virtually any shape as long as they remain a single piece (i.e., not disjointed) and do not contain an enclosed void. Individual department shapes can be controlled through a user-defined shape parameter, one which compares the department's perimeter-to-area ratio to that of the ideal shape, e.g. a square.

2.3 Drawing an Initial Layout

Drawing the initial layout involves doing four basic steps: (a) drawing obstacles, (b) placing fixed departments, (c) drawing the space filling curve, and (d) placing free departments.

The user has unlimited freedom in designating unusable space in the facility. Defining obstacles is the first step in drawing the layout because grids assigned to obstacles may not be visited by the space filling curve.

Another set of grids not visited by the space filling curve is that of fixed departments. Fixed departments should also be drawn before the space filling curve. While fixed departments never move during the optimization run, they are nevertheless different from obstacles because flows exist between them and the other departments.

A space filling curve may then be drawn through the rest of the grids, i.e., those not assigned to either obstacles or fixed departments. The user may experiment with several types (in terms of orientation, density, or path) of curves either to obtain alternative layouts or to correct some department shapes.

To complete the layout, the free departments are then drawn either by sequencing them automatically along the defined space filling curve or by laying them out individually. See Figure 1. Boundaries may also be drawn to outline individual department block footprints.

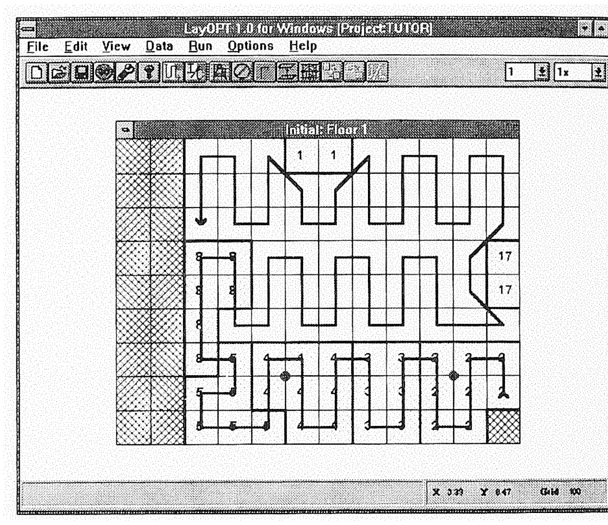

Figure 1: Partially Completed Initial Layout

2.4 Defining Weight Factors and Flows

The objective function minimized by LayOPT is the sum of parts flows multiplied by unit costs and the distances over which these parts travel. Having defined the departments and an initial layout from which distances can be calculated, the From-To chart may be entered directly by the user. Parts flow values entered in this chart may be expressed in different units, e.g., pieces, pallets, trips, racks, etc. However, they should represent parts flow between departments over the same time period.

The user may also enter from-to information using process flow charts. Here, the user graphically specifies departments visited in sequence by each subassembly or component that make up the end products. The quantity of each component that goes into the end product as well as transfer batch sizes are defined for each department pair in the process sequence. LayOPT then automatically generates the From-To chart from these process charts.

In addition to the From-To chart, the user also supplies a cost or weight factor matrix which represents either: (a) the actual unit cost of moving the parts between the departments, or (b) user-defined relative weights. The resulting layout assessment can therefore be either the total material movement cost or the weighted sum of parts travel in the facility.

2.5 Executing an Optimization Run

A LayOPT optimization run can be executed in one of two modes: automatic and interactive. In its true steepest-descent two-way exchange form, the automatic run searches all possible departmental exchange pairs based on space, shape, floor, and other restrictions and selects the best exchange at each iteration. The department location exchange is made and it proceeds iteratively until no further improvement in the objective function is realizable, at which point the optimal layout has been reached.

The interactive run mode allows the user to execute incremental 2-way departmental exchanges on the current layout. LayOPT presents the top 10 exchanges at each iteration in descending order of layout assessment savings and lets the user select the most appropriate (not necessarily the best) exchange. See Figure 2. Once the user selects one of the top ten exchanges, LayOPT switches the locations of those two departments and proceeds to the next iteration. A new list of top ten exchanges is then constructed from the 'new' layout. The user interactively participates in this process until no further exchanges can reduce the current layout assessment.

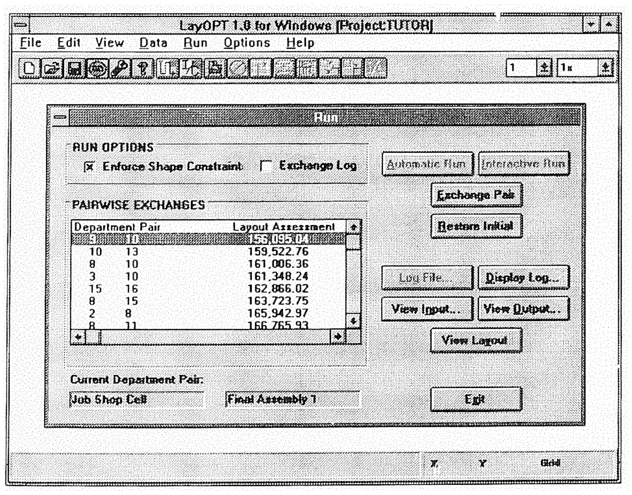

Figure 2: Interactive Run

2.6 Massaging the Final Layout

It is expected that the user will perform multiple runs starting with different initial layouts or space filling curves. This enables the generation of several alternative layouts that in general, satisfy the overall layout development objective. During these runs and in the resulting layouts, some departments may assume irregular shapes. LayOPT allows the user to 'massage' the layout by smoothing out or refining department shapes and make them more practical and usable.

Department shapes can be adjusted through either of the following layout massaging features: (a) even (no area loss/gain) grid exchange between departments, or (b) grid reassignment from one department to another.

Departmental input and output points can also be assigned anywhere within departmental boundaries to designate actual parts pick-up and drop-off points. This allows for a more realistic calculation of the layout assessment summary when presenting actual material handling costs for the final layout.

3 LAYOPT AND SIMULATION

For many facilities layout design or improvement tasks, conventional practice suggests arranging departments in a new plant in the same manner as has been done in similar plants in the past. While this easy approach saves time, it nevertheless runs the risk of inheriting the inefficiencies and shortcomings of the previous layout. On the other hand, most simulation studies attempt to determine satisfactory plant operating parameters based on an existing layout. Increasingly, analysts all too quickly jump to the micro-level simulation of a proposed system laid out inefficiently and perhaps show 10%-15% improvements in WIP levels or material handling costs. In the process, they may have missed a larger window of opportunity to save up to 80% in material movement and handling costs had they first optimized the layout.

The ills of *simulating a bad layout* are numerous and common. In many simulation studies, the objectives are operational and local: (a) how many carriers should a power and free system have to adequately service the needs of the assembly area? (b) how many forklifts does the shipping and receiving area need? (c) what is the best speed to run a particular transfer conveyor? (d) which of two possible temporary staging areas should WIP be sent to and what should the capacity of those staging areas be?

All these objectives focus on the one thing that lean manufacturing is all about: reducing non-value added time spent on material handling or storage systems. To this end, the layout on which the simulation is based should have already addressed the issue of minimizing parts travel distance and cost between departments. No amount of simulating can directly point out that a particular department should not be located where it is at. For instance, a simulation model might recommend six instead of seven forklifts to service the plant but it cannot directly show that by simply moving one department to another location, only two forklifts will be needed. By doing a layout optimization study before any discrete event simulation, it may even show that forklifts are not the most cost-effective way to transport the materials.

What the simulation model can provide, though, is an effective scheme for allocating work among available forklifts. Operational issues such as work scheduling, traffic flow control, break scheduling, and manpower allocation are best addressed by a discrete event model that considers both system capacity constraints and time or resource requirements. In this regard, it is important to emphasize the significance of layout planning in the macro-level, strategic phase (department location and space allocation) and that of simulation in the micro-level, operational phase (resource scheduling and utilization). With LayOPT, developing an optimal layout ensures that the overall cost of moving parts and finished goods between departments is the lowest feasible. It then allows simulation to address the operational issues more effectively, assured that the layout is already the most cost-efficient it can be.

The goal of lean manufacturing is the shortest, most cost-effective product-to-customer time possible. By one measure, that means the smallest, if not zero, non-value added portion in the product manufacturing cycle time. With that common goal, layout optimization and simulation are two complementary tools indispensable to any plant layout and productivity improvement task.

4 SUMMARY

This tutorial presented LayOPT as a Windows-based facilities layout analysis and optimization software package. It was developed to assist layout planners and engineers in solving single and multiple floor facility layout problems. LayOPT overcomes the limitations of current algorithms and generates solutions that are generally 50% to 80% more efficient. With its unique and state-of-the-art, as well as state-of-the-practice optimization engine, LayOPT empowers you to explore many quality alternatives to your facilities layout design challenges.

REFERENCES

Bozer, Y. A., R. D. Meller, and S. J. Erlebacher. 1994. An Improvement-type Layout Algorithm for Single and Multiple-floor Facilities. *Management Science* 40:918-932.

AUTHOR BIOGRAPHY

ERIC S. GRAJO is a senior consultant at Production Modeling Corporation, an industrial engineering and simulation consulting firm based in Dearborn, Michigan. He specializes in computer simulation and facilities layout planning for various manufacturing and material handling concerns in the automotive, electronics, food, pharmaceutical, chemical, and service industries. He led the team responsible for the development and application of LayOPT, a facilities layout optimization software package. Mr. Grajo has a Master's degree and has completed the course work for a Ph.D. in Industrial and Operations Engineering at the University of Michigan.