A Decision Support System for Facility Layout Changes

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Abstract: A manufacturing company attempts to organize its facilities in the most efficient way to serve the particular mission of that plant. Facility layout problem is classified into 2 areas: Green field design and facility re-layout problem (FRLP). Until today, most research on facility layout focuses on green field design whereas the facility re-layout problem is more common than green field design. Since layout change is unavoidable to adapt in today’s dynamic environment, our focus is on the FRLP.

For FRLP, it is necessary to compare existing layout with new changed one in terms of major performance criteria. A matrix-based approach is proposed in this paper, which is a subset of SLP (Systematic Layout Planning) procedure. In this approach, layout alternatives are evaluated procedurally by the criteria of traffic volume∙distance.

Proposed method deals with dynamic aspect by calculating traffic volume for future production schedule rather than only considering static distance reduction.

Key-Words: - Facility Layout, Facility Re-Layout, Layout Change, Traffic Volume, Systematic Layout Planning

1 Introduction

Nowadays the unpredictability of market changes, the growing product complexity and continuous pressure on costs force enterprises to develop the ability to respond and adapt to change quickly and effectively. To cope with these challenges, most enterprises are pursuing continuous improvements such as layout change, reduction of manufacturing lead time, enhancement of machine availability and labor utilization.

A manufacturing company attempts to organize its facilities in the most efficient way to serve the particular mission of that plant. Facility layout change occurs due to following changes: introduction of new parts, introduction of new process method, changes of order quantity and so on. Nicol and Hollier surveyed 33 companies of average size, and nearly half of these companies reported that they had an average layout stability of two years [10]. Facility layouts organized for variable routing can have a variety of possible configurations, so they influence on performance such as material movement cost and total throughput time.

However, layout change is not easy task because it needs additional investment and production delay during layout change period. Since facility layout change has a significant effect on productivity, decision making for facility layout improvement is vital to manufacturing firm’s competitiveness.

Determining the physical organization of a production system is defined to be the facility layout problem (FLP). FLP is classified into 2 areas: Green field design and facility re-layout problem (FRLP). Most of the literature on facility layout focuses on green field design, which is a design of a new facility without influence or constraint of an existing facility. In practice, the FRLP is more common than green field design since both manufacturing and service industries operate in highly volatile environment which motivate them to redesign their layouts [5].

The approaches to the new layout design often fall into two major categories as algorithmic and procedural approaches [16]. Algorithmic approaches usually simplify both design constraints and objectives in order to reach a surrogate objective function. Major solution methodologies are exact procedure, heuristics, meta-heuristics, and other approaches such as neural network and fuzzy logic [12].

Procedural approaches can incorporate both qualitative and quantitative objectives in the design process. For these approaches, the design process is divided into several steps that are then solved sequentially. Most famous methodology is Muther’s system layout planning (SLP) which has 11 steps for layout creation [8]. The SLP begins with PQRST analysis for the overall production activities. The type of data collected includes P (Product), Q (Quantity), R (Routing), S (Supporting Service), and T (Timing).

Besides these two approaches, Han et al. proposed...
parametric layout design of FMS (Flexible Manufacturing System) [4]. FMS layout in this approach is determined rapidly by choosing standardized design parameters in each FMS station. It reflected the today’s trend that modern automated manufacturing systems have a modular and hierarchical structure and are constructed by ‘assembling’ standard resources (or catalog items).

Since layout change is unavoidable to adapt in today’s dynamic environment, our focus is on the FRLP. For FRLP, it is necessary to compare existing layout with new changed one in terms of performance criteria. Methods for layout alternatives evaluation fall into 3 categories: 1) simulation approach, 2) AHP (Analytic Hierarchy Process)/DEA (Data Envelop Analysis), and 3) Hybrid approach integrating simulation with AHP/DEA.

Simulation is a useful tool for evaluating the multiple performance measures in a complex system. Various performance measures with different dimensions have been selected for the simulation analysis of facility layout change.

The AHP is one of the most widely used multi-criteria decision making methodologies due to its simplicity, ease of use and flexibility. Layout alternative evaluation can be performed by quantifying intangible aspects and relative measurement. DEA is one of efficiency measurement method based on linear programming when there is a difficulty to the comparison of direct causal relationship between multiple inputs and outputs.

The main objective of this paper is to propose a new approach for the evaluation of layout change alternatives. It is a matrix-based approach, which is a subset of SLP procedure, in which several matrices are constructed and layout alternatives are evaluated procedurally by the criteria of total traffic volume multiplied by distance within a facility layout.

The rest of the paper is organized as follows. Section 2 reviews related works. Section 3 describes a proposed matrix-based approach and its application. Finally, the last section summarizes results and suggests directions for future research.

2 Related Works
A state-of-the-art review were made on facility layout problems to deal with the current and future trends of research on FLPs based on previous research including formulations, solution methodologies [2, 5, 6, 7, 12]. However, all of these review papers focused on the solution of green field design of facility layout. Only Kulturel-Konak addressed that facility re-layout design is needed as a future research directions [5].

Since algorithmic approach requires for advanced training in mathematical modeling techniques, SLP was adopted in industries as a viable approach in the past few decades. Yang et al. applied the SLP as infrastructure and the AHP for evaluation of the design alternatives to solve a fab layout design problem [16]. Van Donk and Gaalman also applied the SLP to layout planning of food industry, in which hygienic factors were dealt additionally [14]. Cellular manufacturing layout design based on SLP and selection of facilities layout design by AHP was applied to a case study of an Electronic Manufacturing Service (EMS) plant [9].

As mentioned in the first section, evaluation methods for layout alternatives in FRLP fall into 3 categories: 1) simulation approach, 2) AHP (Analytic Hierachy Process)/DEA (Data Envelop Analysis), and 3) Hybrid approach integrating simulation with AHP/DEA. Among these, simulation approach is most popular due to its capability of multiple-criteria performance evaluation. Simulation model using ProModel was proposed to assist decision making on expanding capacity and plant layout design [13]. Major criteria for alternatives evaluation are machine utilization and WIP (Work In Process) level.

The performance evaluation of current and re-designed layout was presented by using ARENA [1]. In this approach, redesigned layout was developed by means of rank order clustering and CRAFT.

Within the second category, Gao applied the AHP and DEA to facility layout selection [3]. In this approach, pure output DEA is used to construct the comparison matrix, and then AHP is applied to calculate the weights of the alternative locations. Yang and Kuo proposed a hierarchical AHP and DEA approach to solve a plant layout design problem [15]. Qualitative performance measures were weighted by AHP. DEA was then used to solve the multiple-objective layout problem.

As a hybrid approach, Xu et al. presented case study that integrates a simulation study with AHP, applied to the layout design of a transmission line in a Korean automotive company [17]. Shahin proposed an integrated approach of simulation, fuzzy AHP and Quality Function Deployment (QFD) and Multiple Criteria Decision Making (MCDM) for facility layout design improvement and optimization [11]. In this approach, computer simulation has been used to
3 Matrix-based Approach and Implementation

Usually, the layout is planned to minimize a particular criterion: Major criterion in this paper is the total traffic volume multiplied by distance within a facility layout (Total Traffic-Distance: TTD). In order to evaluate the performance of as-is and to-be layout in terms of TTD, 3 matrices should be constructed in the proposed approach: First of all, scheduled production quantity of each part should be converted to transportation units (TUs) to calculate the traffic volume. The TU is the number of containers for a specific part to be moved between machines.

\[ TU_x = \left( \frac{PQ_x}{UTQ_x} \right) \]  

where \( TU_x \) = number of transportation units of part \( x \), \( PQ_x \) = scheduled production quantity of part \( x \), \( UTQ_x \) = unit transportation quantity, i.e., container capacity for a specific part to be moved in one time between machines.

1) Traffic volume matrix (T)
where \( T_{ij} = \sum_{x=1}^{n} (\sum_{i=1}^{m} \sum_{j=1}^{m} (i \cdot j) \cdot TU_x) \) (\( i=1 \) and \( j=1 \) when there is a process route from \( i^{th} \) to \( j^{th} \) facility to produce part \( x \), otherwise \( i=0 \) and \( j=0 \);
\( n=\)number of parts; \( m=\)number of facilities).

2) Distance matrix (D)
where \( D_{ij} = \)distance from \( i^{th} \) facility to \( j^{th} \) facility.

3) Traffic-Distance matrix (TD) where \( TD_{ij} = D_{ij} \cdot T_{ij} \)

Based on 3 matrices, total traffic-distance (TTD) between facilities of a specific layout is calculated as:

\[ TTD = \sum_{i=1}^{n} \sum_{j=1}^{m} TD_{ij} \]  

By using TTD, proposed method deals with dynamic aspect for future production schedule rather than only considering static distance reduction.

Proposed matrix-based approach is rooted in SLP concept. Among 11 steps of SLP, our approach follows 3 steps which are step 1, step 2 and step 11.

3.1 Matrix-Based Approach for Facility Layout Alternatives Evaluation

Developed system in this paper is called decision support system for layout change (DSS4LC), which consists of 3 parts. And it is an MS Excel spread sheet application in which VBA (Visual Basic for Application) functionalities are added.

First part of DSS4LC is master data preparation. Master data is comprised of process plan, from-to distance matrix of as-is layout, and unit transportation quantity (UTQ) data. In a job shop manufacturing system, layout type is usually a process layout where similar pieces of equipment that perform similar functions are grouped together. For example, all drill machines are grouped and placed together. In process layouts, a variety of different products are manufactured in small and medium batch sizes. Therefore, there exist complex routings among machines within a process plan.

The UTQ is the quantity of parts to be moved in one time between machines dependent on the part geometry and transporter characteristics. It is used for calculating traffic volume of each part.

Second part is input data for to-be layout alternative. It consists of master production schedule (MPS) and from-to distance matrix for to-be alternative layout. The planning horizon of MPS can be a month, quarter or half-year. And process plan in the master data can be modified or added to reflect the environmental changes as an input data.

Third part is evaluation report which compares as-is layout with to-be layout in terms of following criteria: TTD (Total traffic-distance), top 5 from-to distance, and top 5 from-to traffic-distance between facilities.

3.2 Case Study

“Company S” in this case study mainly produces agricultural and construction machinery parts in Korea. Its production characteristics include high product varieties (over 300 different part types) and small production volumes. As a result, it has adopted a process layout and batch production system which makes routings more complex. There are wide varieties of process route from one to sixteen steps required to produce one part. Part of process plan is shown in Figure 1.

Usually, 200 parts is monthly produced in S company. In the case study, monthly production schedule is prepared for 50 parts which majorly
influence on TTD of to-be layout. And distance matrix is built up for 75 machines.

Major reason of the layout change in the case study is the introduction of new parts for construction machinery. The location changes between machines occur usually between workstations. In the to-be layout of case study, locations of 19 machines are changed as shown in Figure 2: 14 machines are re-located between workstations, and 5 machines are re-located within workstations. In Figure 2, line intensity represents the number of facilities relocated. Unbroken line represents inter-workstation changes, and dotted line represents intra-workstation changes.

Monthly master production schedule and UTQ of each are shown in Figure 3. For example, monthly production quantity of part no. 8011 is 781, and its UTQ is 30. Therefore, 27 transportation units (TUs) will be moved for the processing of part no. 8011 in this schedule.

By using the constructed 3 matrices, TTD is calculated in the evaluation report. The TTD of to-be layout (8,320) has 3.5 (%) improvements compared with as-is layout (8,026) as depicted in Figure 4.

Besides TTD, evaluation report provides additional information as follows: 1) Top-5 traffic volume between facilities. It has no difference between as-is and to-be layout because the input data of MPS and UTQ is same. 2) Top-5 distance between facilities of as-is and to-be layout. In the case study, average of top-5 distance between facilities is reduced from 18.8 meters of as-is to 17.2 meters of to-be layout. 3) Finally, top-5 traffic-distance between facilities. Using these detailed criteria, engineers can investigate the effect of new changed layout with various perspectives.
than number of part types because new layout must reflect the dynamics of production environment such as production quantity, process plan and UTQ. However, it is difficult to calculate traffic volume intuitively. Therefore, computer-based tool such as DSS4LC in this paper is needed.

By using DSS4LC, layout engineers can have synthetic views considering distance and traffic volume in layout changes simultaneously.

4. Conclusions and Further Research

Manufacturing industries are under great pressure caused by the rising costs of energy, materials, labor, capital, and intensifying worldwide competition. In other words, external environment of enterprise are rapidly changing brought about majorly by global competition, cost and profitability pressures, and emerging new technology.

In particular, to achieve a fast response to market changes in today’s time-based competition environment, it is quintessential to change the facility layout rapidly and easily. The layout decision will certainly affect the flow of materials, in-plant transportation cost, equipment utilization, and general productivity and effectiveness of the business. Therefore, plant layout should be carefully arranged.

Until today, most research on facility layout focuses on green-field design whereas the facility re-layout problem is more common than green field design. Proposed method is a practical approach for layout changes without requiring deep mathematical knowledge, which is based on SLP concept. This system deals with dynamic aspect by calculating traffic volume for future production schedule. By using developed system in this paper, layout engineers can evaluate the effect of changed layout alternative with various perspectives and in less time.

However, current system has a time-consuming task of distance calculation between facilities for distance matrix. Therefore, as a further research, automatic distance calculation from the CAD file with constraint of existing path is required.

References


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