International Journal of Industrial Engineering, 18(5), 260-269, 2011.

DESIGN AND IMPLEMENTATION OF LEAN FACILITY LAYOUT SYSTEM OF A PRODUCTION LINE

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Considering that the unreasonable facility layout of a production line directly or indirectly leads to low production efficiency is very common in Chinese manufacturing workshops, facility lean layout system of a production line is researched and designed. By analyzing the influencing factors of the facility layout system, optimization objectives and constraint conditions of facility layout system are summarized. A function model and a design structure model of the studied lean facility layout system are built. Based on the in-depth analyses of the mathematical model designed to denote the layout optimization design of a production line, a prototype lean facility layout system of a production line is developed. The application results of the designed facility layout system in cylinder liner production line show that the designed lean facility layout system can effectively enhance the production efficiency and improve the use efficiency of the equipments.

Keywords: production line, lean, facility layout, model, design

(Received 25 March 2009; Accepted in revised form 9 September 2010)

1. INTRODUCTION

Facility layout is an important problem for modern manufacturing systems and it plays a key role for the manufacturing system design process. Lean facility layout means to arrange the physical equipments within a workshop to help the facility work in a productive way. A good layout scheme would contribute to the overall efficiency of operations. the research on facility layout of a production line has always been the key research area of industrial engineering domain((Diego-Mas et al., 2009); (Ramazan, 2009); (Raman et al., 2009) ;(Zhang et al., 2009)). The facility distribution form of a production line depends on the type of the enterprise and the production organizational mode ((Amaral,2008);(Khilwani et al., 2008)).

Traditionally, there are two approaches for the facility layout problem (Sahin et al., 2009). The first one is the quantitative approach aiming at minimizing the total material handling cost between departments based on a distance function. The second one is the qualitative approach aiming at maximizing closeness rating scores between departments based on a closeness function. The most important example for this approach can be systematic layout planning-SLP procedure, suggested by Muther (Muther, 1988). In recent years, with the improvement of the computer performance and the development of the digital analysis methods, computer-aided system layout planning (CASLP) method appears based on applying computer and its related technologies to SLP method (Lan et al., 2005). The CASLP method not only greatly speeds up the layout plan process, but also provides simulation display of the designed layout scheme depending on the advanced functions of people-machine-interaction and computer aided drawing technology.

The changes of production planning, technological process, production organizational mode and material handling will all affect the facility distribution scheme of a production line (JIA et al., 2006). The approaches stated above were used separately to solve the facility layout problem. However both approaches have advantages and disadvantages. In order to do a lean layout design, we need to solve the problem by using a new method. The research content of this paper is a part of the Lean Production project originated by Chinese Dalian Refrigeration Co. Ltd. A detailed machining process of a production line is recorded firstly; then based on the analyses of the technological process and combined SLP method with computer simulation technology, a lean facility layout scheme of the production line is achieved; finally, working standard of the production line with the designed lean facility layout scheme implemented is established.

2. THE LEAN FACILITY LAYOUT SYSTEM DESIGN

2.1 Function Model and Design Structure Model of the Layout System

Fig.1 shows the function model of the lean facility layout system of a production line. The designed lean facility layout system is comprised of four function modules: information management module, workshop drawing module, facility layout module and layout simulation module. Information management module achieves the data storage and operation management of the equipment, technical process, workers, parts, etc. Workshop drawing module extracts the concerned data from the data base and fulfills the drawing of the workshop doors, operating aisles and facilities, finally achieves drawing of the workshop framework; Facility layout module includes three parts: the initial layout, the preliminary optimization layout and the lean layout. The initial layout shows the practical facility layout of the production line. Through the analyses of the quantity of the parts and the technical process, the preliminary optimization layout section realizes the improvement of the initial layout scheme; considering the production organization mode, material handling and the concept of lean production, the lean facility layout scheme is proposed in the lean layout section of the facility layout module. Simulation results of the different layout schemes verify the rationality and superiority of the final lean facility layout scheme.

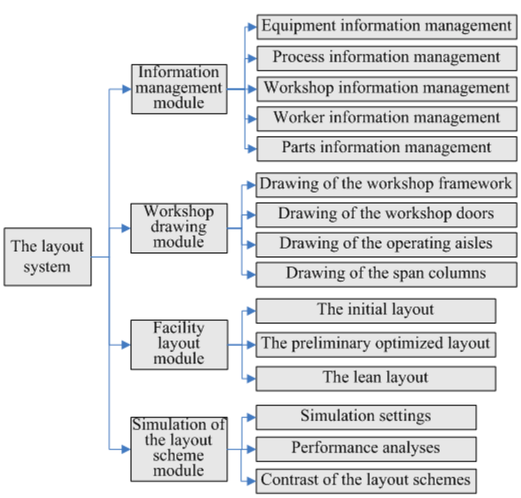

Figure 1. The functional components of the system

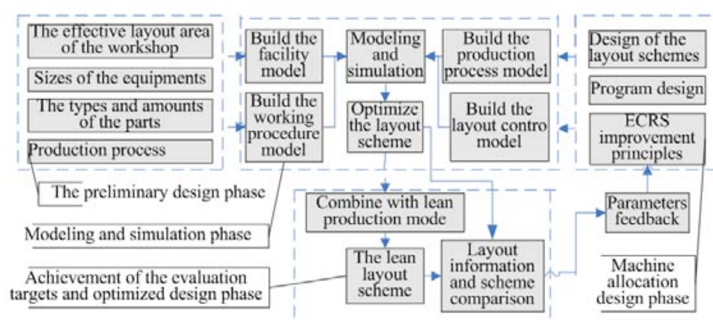

Figure 2. Design process of the system

2.2 Design Process of the System

Fig.2 shows the design process of the system, which is divided into four phases: the preliminary design phase, layout design phase, modeling and simulation phase, achievement of the evaluation targets and optimization design phase (WANG et al., 2007).

The preliminary design phase mainly actualizes the collection of the effective information such as the layout area of the workshop, spacial dimension of the facilities, the types and amounts of the parts, the technical process, etc., and then establishes the database of the layout system. Based on the established database, layout design phase selects technical process as the study object and analyzes the integrated process flowchart in detail. According to the ECRS (Elimination-Combination-Rearrangement-Simplification) improvement principles, layout design phase conducts the recombining of the program and achieves the optimum layout scheme. Modeling and simulation phase abstracts the composition elements of a production line and builds the layout model to simulate the practical layout status, the improved layout status and the final lean layout status of the production line. Through the evaluation targets' comparison among the different layout schemes, achievement of the evaluation targets and optimization design phase achieves the evaluation of the different layout schemes. The evaluation results can offer reference to further optimization layout plan of a production line. The design process of the system can provide guidance for the detailed code design of the system.

3. MODELING OF THE LEAN FACILITY LAYOUT SYSTEM

A production line is usually comprised of many machining facilities, different facilities complete different working procedures. Technical process information of a part can be seen as the collection of working procedures. Working procedure generally has two attributes: working hours (i.e., the time required to complete the machining task, which includes clamping workpiece hour, machining hour and unloading hour) and working machines that implement the machining task. The states of the working machines are simply divided into busy and idle in the system: busy state denotes the working machine is conducting a working procedure and the parts are waiting for the working machine to finish the machining task. After a working procedure is finished and the workpiece is unloaded from the machine, the state of the machine changes into idle. Then the machine selects the machining operation, which has the highest priority, from the waiting queue of parts to execute the processing operation, and the state of the machine changes into busy. The states of the working machines change repeatedly as the above mentioned process.

The studied facility layout scheme should minimize the waiting hour of a machining task; reduce the transfer distance of the workpieces; be avail of conducting OWMM (One Worker, Multiple Machines) operation. The designed lean facility layout system should be able to obtain the state of each working machine; calculate the waiting hour of each machining task, point out the bottleneck procedure and bottleneck equipment, calculate the transfer distance, and conduct lean analyses on the facility layout scheme of a production line.

3.1 Simulation Elements of the System

Facilities and the materials' buffers are defined as permanent entities in the lean facility layout system; the workpieces that enter the production line and wait for processing are defined as temporary entities. The temporary entities' changes will lead to changes of the buffers queue length and the states of the machining equipments.

The states of the temporary entities include: the state that the workpieces complete machining processing and need to leave the current machining equipment; the state that the workpieces queue in the current buffer and wait for the facility to finish its machining task; the state that the next working procedure buffer is full and the workpieces need to wait, and so on. The attributes of the event is used to denote the states of the temporary entities in the program, figure "○" is adopted to describe workpieces, and the red "○" expresses automatic machining operation while the blue "○" implies manual processing. The states of the permanent entities include: the state that the machining machine is busy; the state that the machining machine is idle; the state that the machining machine is wrong; the state that the machine is waiting for the workpiece to leave; the states of buffer, etc.

The events of the system include the arrival of the workpiece, the leaving of the workpieces and the events' compulsive terminating by the program. Timer is selected to denote the changes of the simulation clock.

3.2 Modeling Rules

The modeling rules of the lean facility layout system are as follows:

1) Each device can only conduct one part machining every time;

2) Part machining sequence is in accordance with the equipment number;

3) Part machining time is definitive;

4) Facilities' machining capacity can be adjusted in a certain range;

5) The simulation time of a part entering the production line is predetermined.

3.3 Simulation Mathematical Model of the System

The simulation mathematical model of the layout system considered in this paper only includes layout in one line model and layout in multi-line model, while the ringlike layout model and U-type layout model are considered as special cases of single-line layout model. The linear double-line layout model is considered as a special case of multi-line layout model.

Layout in One Line Model

The assumptions are as follows:

1) The shape of the machining machine is square or rectangular and its 3D dimension is known;

2) The equipments stand in a line;

3) The orientation of the equipment is known.

The relationship between the two equipments layout in one line is shown in Fig.3, and the symbols specification is as follows:

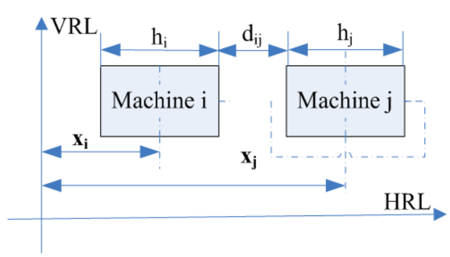

Figure 3. The variables of the layout in one line model

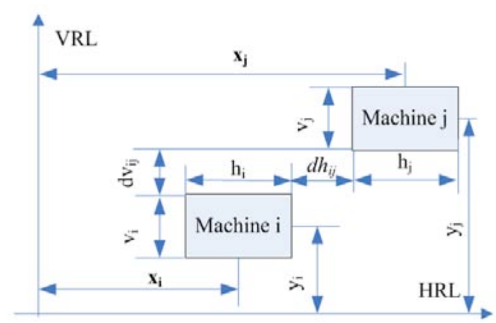

Figure 4. The variables of the layout in multi-line model

m : Equipment numbers;

S_{ij}: The cost for a standard unit weight moving a standard unit distance between equipment i and equipment j;

n_{ij} : The round trip times of material handling equipment moving between equipment i and equipment j;

h_i : The horizontal length of equipment i;

d_{ij} : The minimum distance between equipment i and equipment j in the horizontal position;

H : Horizontal ground;

x_i : The distance between equipment center and vertical reference line.

In the layout in one line model, the decision variable x_i is considered firstly, then the distance d_{ij} between equipment i and equipment j is considered, the model of layout in one line is described as:

$$\min \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} s_{ij} n_{ij} \left| x_i - x_j \right| \qquad \text{...} \qquad (1)$$

Constraint condition: $$\left| x_i - x_j \right| \geq \frac{1}{2}(h_i + h_j) + d_{ij} \qquad \text{...} \qquad (2)$$

Thereinto, i =1, 2, 3… m.

Layout in Multi-line Model

Layout in multi-line is a combination of continuous optimization along X axis and combinatorial optimization along Y axis. For simplicity, we assume that 3D dimension and the orientation of the equipment are known. The decision variables and the relevant relationships of the layout in multi-line model are presented in Fig.4:

m : Equipment numbers;

s_{ij} : The cost for a standard cell weight moving a standard unit distance between equipment i and equipment j;

n_{ij} : The round trip times of material handling equipment moving between equipment i and equipment j;

x_i : The distance between the center of equipment i and the VRL (Vertical Reference Line);

y_i : The distance between the centers of equipment i and the HRL (Horizontal Reference Line);

h_i : The horizontal length of equipment i;

v_i : The vertical length of equipment i;

dh_{ij} : The horizontal distance between equipment i and equipment j;

dv_{ij} : The vertical distance between equipment i and equipment j;

Layout in multi-line model can be described as following:

$$\min \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} s_{ij} n_{ij} \left(\left| x_i - x_j \right| + \left| y_i - y_j \right| \right) \qquad \text{...} \qquad (3)$$

At the same time, below restrictions should be satisfied:

$$\left|x_i - x_j\right| + Mz_{ij} \geq \frac{1}{2}(h_i + h_j) + dh_{ij} \quad \cdots \quad (4)$$

$$\left|y_i - y_j\right| + M(1 - z_{ij}) \geq \frac{1}{2}(v_i + v_j) + dv_{ij} \quad \cdots \quad (5)$$

$$z_{ij}(1 - z_{ij}) = 0 \quad \cdots \quad (6)$$

Thereinto, i, j = 1, ..., m.

Constraint condition Eq. (4), Eq. (5) and Eq. (6) ensure that the equipments will not overlap both in horizontal direction and in vertical direction. The value of z_{ij} in Eq. (6) is 1 or 0, so as to guarantee the validity of either Eq. (4) or Eq. (5).

4. SIMULATION OF THE LAYOUT SYSTEM

4.1 The Main Simulation Flow of the Layout System

Analyzing the layout system in view of the events, the main simulation flow of the layout system is shown in Fig.5. The process begin, the process end and the other events have been listed in the event table. The simulation timer is driven by events**.** The current event anticipates the occurrence time of the other events according to the specific law, and chooses the latest event as the next event according to the "Most Recent First" law. The simulation timer is pushed forward to the occurrence time of the latest event. The arriving and leaving events of machining tasks push the simulation flow of the layout system forward until the machining task is finally finished, then the simulation is over.

4.2 Simulation of Workpieces' Arrival and Departure Events

The simulation flow chart of workpieces' arrival and departure event is shown in Fig.6. The workpiece's arrival event, which refers to that a workpiece moves from the warehouse to the workshop or moves from the previous process to the next process, includes the parts arriving at the machine tools directly or waiting in the storage buffer queue. When a part arrives at the a machine, machining task flow begins to be analyzed and designed based on simulation of the workpiece's arrival event, and then the occurrence time of the workpiece's leaving event is predicted.

The workpiece's departure event refers to that a workpiece moves to the next machining process or leaves the system after the machining task is finished. Firstly, judging weather the machining task is completed when a workpiece is about to leave an equipment; if the machining task of this working procedure is finished, then judging whether there still exist unfinished working procedures, so as to make sure whether the workpiece will exit the simulation system or will move to the next process.

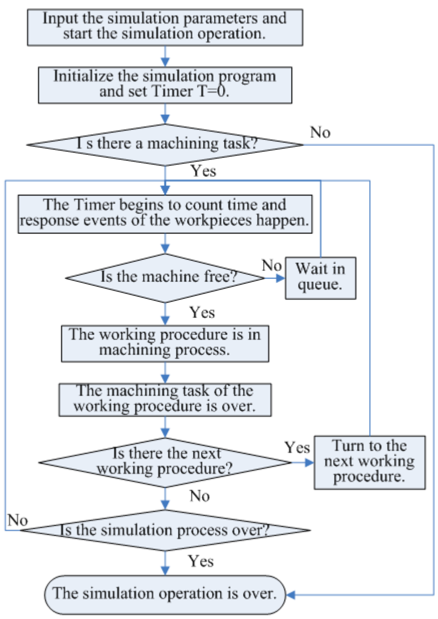

Figure 5. Simulation flowchart of the layout system

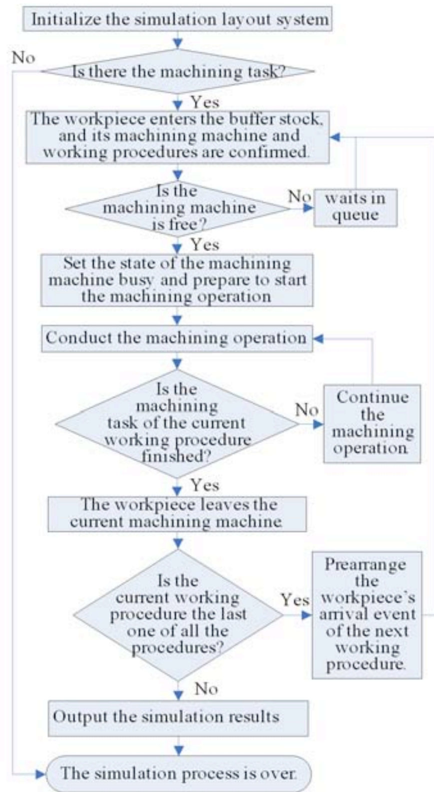

Figure 6. A workpiece's arrival and departure event

5. INDUSTRY APPLICATION

The layout system realizes all process with Visual C++ programming language, corresponding data tables are established with SQL Server 2000, and ADO technology is adopted to realize data access. The OpenGL technology is used in graphic drawing of the system.

The layout simulation module performs simulation of the layout scheme when the system needed parameters are inputted. DataView of the layout system is responsible for operating and displaying data information that the layout system needed. LayoutView is in charge of displaying the layout scheme and simulation information. Taking the lean layout design of the production line in the machine workshop of Chinese Dalian Refrigeration Co. Ltd. **(**JIA et al., 2006**)** for an example, the initial layout scheme realized by the system is shown in Fig.7.

In order to compare the performance of the preliminary optimization layout scheme with the lean layout scheme, the designed layout system realizes the dynamic simulation of the practical layout scheme, the preliminary optimization layout scheme(Fig.8) and the final lean layout (Fig.9). Fig.10 is the comparison results of the initial layout scheme, the preliminary optimization layout scheme and the lean layout scheme. The comparison results clearly reflect the superiority of the lean facility layout scheme of the production line.

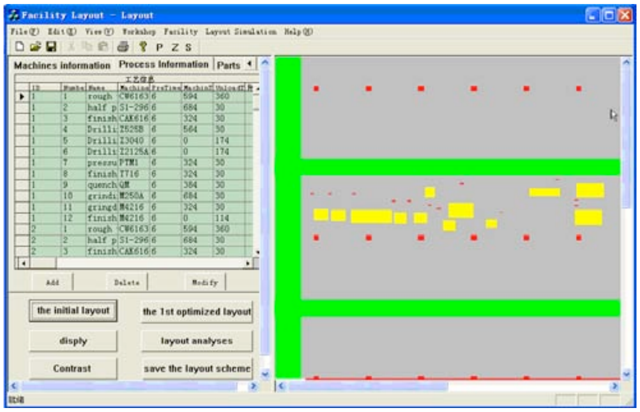

Figure 7. The initial layout

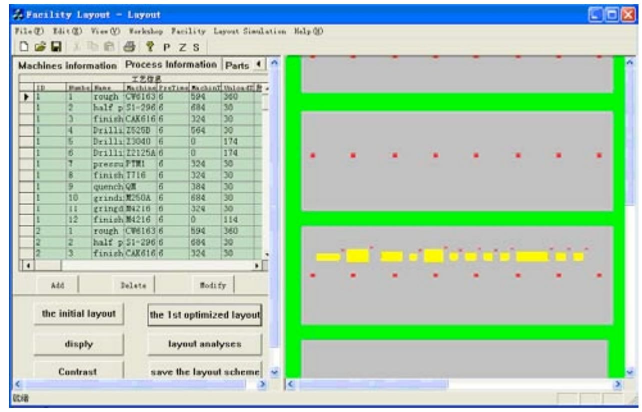

Figure 8. The preliminary optimization layout

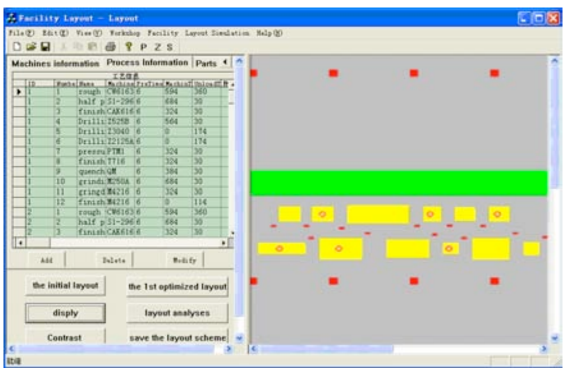

Figure 9. The Lean layout

Comparision of the layout simulation results

	The initial layout	The preliminary optimization layout	The final lean layout
the overall production time of the production line [s]	60300	42700	42700
the theoretical production time of the all working procedures[s]	213600	213600	213600
the overall waiting time of the parts[s]	15313200	10363200	10361200
The waiting ratio of the all equipments	99.63	99.55	91.7%
moving distance of the parts[m]	3883.1	3211.2	2998.1

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Figure 10. The comparison results

6. CONCLUSION

Based on the theoretical research and method research of facility layout, a lean facility layout design system of a production line is studied and developed, which is also under the guidance of lean production concept and computer simulation technology. The design process model and the functional model are built. Applying the lean facility layout system to a cylinder production line and the U-type layout scheme is realized by the system, which can relieve the stress of the tedious job, increase the utilization ratio of the equipments, reduce waste of human resources and equipment resources, and improve production efficiency. If expert system and artificial neural network technology are applied to the designed layout system, expert system and artificial neural network technology on the basis of artificial intelligent technology and making the layout design algorithm would have the ability of self-learning, self-adapting and self-organization, then the lean facility layout system would realize the target of lean and intelligent design indeed, which is the one of the most important research direction in our following research.

ACKNOWLEDGMENT

The author would like to thank all the members of the Lean Production Project team for their help in contributing to the completeness of this paper. The research is supported by the National High-Tech. R&D Program for CIMS, China under project number 2003AA414022. The financial contribution is gratefully acknowledged.

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