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Production Line Layout Planning Based on Complexity Measurement

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Abstract**—**Mass customization production increases the difficulty of the production line layout planning. The material distribution process for variety of parts is very complex, which greatly increases the cost of material handling and logistics. In response to this problem, this paper presents an approach of production line layout planning based on complexity measurement. Firstly, by analyzing the influencing factors of equipment layout, the complexity model of production line is established by using information entropy theory. Then, the cost of the part logistics is derived considering different variety of parts. Furthermore, the function of optimization including two objectives of the lowest cost, and the least configuration complexity is built. Finally, the validity of the function is verified in a case study. The results show that the proposed approach may find the layout scheme with the lowest logistics cost and the least complexity. Optimized production line layout planning can effectively improve production efficiency and equipment utilization with lowest cost and complexity.

Keywords**—**Production line, layout planning, complexity measurement, optimization, mass customization.

I. Introduction

THE modern production system is a complex discrete manufacturing system, and it has the characteristics of dynamic and complexity. The production layout planning is the arrangement of equipment, operations, and transportation paths. It has major influence on plant productivity. Therefore, the purpose of layout planning is to find the most effective facility arrangement and minimize the material handling [1]. However, it is difficult to balance the cost/time-reduction and quality/ flexibility-decline, for massive customized producing-model [2]. The core idea of mass customization is to meet the market's demand for individual products in terms of the efficiency and cost of mass production. Excellent manufacturing system layout design can effectively reduce the material handling costs, shortening the production cycle.

For companies to meet the market demand for product diversification, while ensuring lower production costs, there are two important issues that need to be focused in the design stage of the production line layout. Firstly, the layout of the equipment is fixed, and the process routes of different parts are quite different. Logistics distribution is so complex that the incidence of distribution error will increase. The complexity of the logistic must be reduced. The logistics system is based on a defined system configuration, so the effective method is to reduce the configuration complexity of the production line. Secondly, in the manufacturing industry, material handling costs account for a large proportion of total operating costs. Simultaneously, in a production cycle, the waiting time of material in the workshop accounts for 90% to 95% [3]. Under the premise of meeting the demand of production materials, how to reduce the cost of material distribution and improve the efficiency of material distribution is an urgent problem to be solved. Increasingly intense market competition and growing demand for personalization bring a variable volume, multi-species, dynamic, and volatile market. Since the reorganization of facilities is always expensive and destructive, the key of continuous development is to conform the layout of the facilities to the dynamic and volatile market-demand. Hence, it is of great significance to research the production line layout planning considering the logistic cost and configuration complexity simultaneously.

This paper demonstrates an approach which is used to optimize the production line layout to meet the demand of mass customization based on configuration complexity measurement especially the information entropy. The structure of this work is essentially in four parts. Firstly, the related literature review for production line layout planning and complexity measurement is primarily presented in Section II. Then, the proposed approach is presented to illustrate the function model of optimization in Section III. Furthermore, a case is used to validate the approach in Section IV. Finally, discussion and conclusions appear in Sections V and VI.

II. Related Works

In the field of production line layout planning, many researchers have completed a lot of work. Huang et al. [4] proposed an optimal design method for production line layout to minimize the total cost including work in progress (WIP) holding cost, buffer allocation cost, and material handling cost considering buffer allocation. Gao et al. [3] proposed a two-step resolution for facility layout planning by integrating fuzzy theory with system simulation to solve layout and scheduling problems of manufacturing system. The effective construction of the facilities layout between the units is realized by the computer simulation technology. Taha et al. [5] integrated two optimization models such as: layout and sequence optimization to those factories that want to produce the various kinds of products with fixed and changeable machine locations. Suemitsu et al. [6] study the multi-robot cellular manufacturing

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systems and proposed a new layout design optimization method for robotic cellular manufacturing system layouts that can simultaneously determine the positions of manufacturing components and also task scheduling considering the sequence of tasks the robots conduct during the assembly process. Berlec et al. [7] presented a method of layout planning that rearranges production resources and minimizes work and material flow transfer between production cells. The method is based on self-organizing map clustering which organizes the production cells into groups sharing similar product properties. The method is particularly suitable for improving the existing layouts. Prasad et al. [8] selected a number of stations in the after-test assembly and after-paint assembly for capturing the production process requirements. Then, failure mode and effects analysis of after-test assembly is carried out aiming at reducing the costs, maintaining the quality, and designing the plant layout that is flexible to meet the customer demand. With the improved layout, considerable reduction in the distance moved by the operator has resulted in 20%. Papadaki and Chassiakos [9] developed feasible and efficient site layout solutions in a realistic representation scheme taking into consideration not only the total distance traveled but also cost and safety parameters as well. A multi-objective optimization model is developed aiming at minimizing a generalized cost function which results from the construction cost of a facility placed at alternative locations, the transportation cost among locations, and any safety concern in the form of preferred proximity or remoteness of particular facilities to other facilities or work areas.

In modern manufacturing environment, the main trend of production line planning is to optimize production costs, such as logistics costs, storage costs. The method is to define the internal structure of manufacturing system, optimize the internal material flow. However, the complexity of the material flow is rarely considered. It increases along with the varieties of the products which are produced in a production line. The material distribution becomes increasingly hard, and the distribution error rate will be increased correspondingly. In recent years, the complexity theory has provided an effective means for quantifying the complexity.

Some research has been conducted in the configuration complexity measurement area by integrating the process information. Wang et al. [10] proposed a multi-objective optimization approach to balance product variety and manufacturing complexity when designing a product family and the mixed-model assembly system. Relative complexity is introduced to measure the complexity and to find the best set of product variants to be offered while balancing market share and complexity. El Maraghy et al. [11] proposed a code-based structural complexity index to capture the amount and variety of information related to the machines, buffers and material handling equipment in manufacturing systems. The probability of a manufacturing system's success in delivering the desired production capacity, as function of the availability of its components, is used as an additional measure of the system complexity in meeting the targeted forecast production volume with its variation.

III. Production Line Layout Planning Model Based on Complexity Measurement

This section aims at providing a detailed derivation procedure of production line layout planning model based on configuration complexity measurement.

A. Problem Description

There are different kinds of machines in a production line, such as drilling machine, grinding machine, lathe machine, milling machine, and so on. Every part to produce has its own process route. In order to complete the production process of many different kinds of parts, many works in progress may flow forward and back several times. That is to say, there are many times that the loop is traversed during the process. However, in the design stage of the production line, there are many alternatives of layout. The main aim of production line layout planning is to find out the optimal design of the line layout with high delivery efficiency, and less distribution errors.

B. Production Line Layout Planning Model

In a production line, there are many kinds of machines, and every machine is fixed. Fig. 1 presents the location of the machines in a common production line.

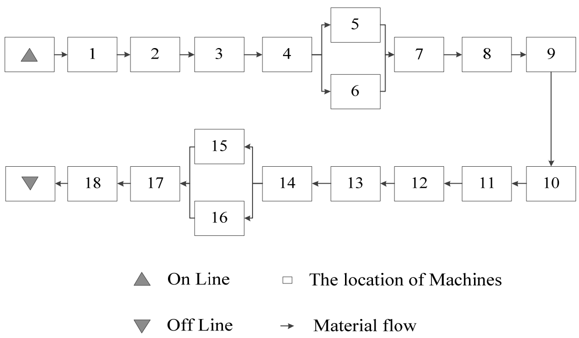

Fig. 1 The location of machines

Distance matrix shows the distance of machines:

$$D = \begin{bmatrix} d_{11} & d_{12} & d_{13} & \cdots & d_{1m} \\ d_{21} & d_{22} & d_{23} & \cdots & d_{2m} \\ d_{31} & d_{32} & d_{33} & \cdots & d_{3m} \\ \cdots & \cdots & \cdots & d_{ab} & \cdots \\ d_{m1} & d_{m2} & d_{m3} & \cdots & d_{mm} \end{bmatrix} \quad (1)$$

where, d_{ab} presents the distance between machine a and machine b.

If the process of part i needs to be completed, it should flow along with the *route*(i).

$$route(i) = [a_1, a_2, \cdots a_r \cdots a_{su}] \quad (2)$$

where, a_r is the machine r. The number of machines in the route is su.

The length of $route(i)$ is $L_{route(i)}$:

$$L_{route(i)} = \sum_{r=1}^{su-1} d_{a_r a_{r+1}} \tag{3}$$

The weight of part i is W_i. n is the type number of the parts variety. The number of the part i is N_i. Then, the cost of the part logistics is C:

$$C = \sum_{i=1}^{n} L_{route(i)} \cdot W_i \cdot N_i \tag{4}$$

Information theory provides a well theoretical basis to measure the uncertainty which is a function of probabilities. $P(x)$ presents the success probability of a single process route which is related to the distance of machines.

$$P(x) = P(route(i)) = \prod_{r=1}^{su-1} p(r) \tag{5}$$

where $p(r)$ presents the success probability of material transferring from machine r to machine r+1. For example, Fig. 2 presents the material flow diagram of a process route. The process route is (1, 2, 3, 4, 2, 6, 5, 7).

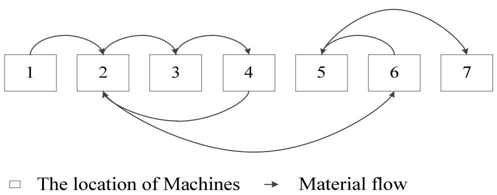

Fig. 2 The material flow diagram of a process route

The configuration complexity is H_{cms}:

$$H_{cms} = -\sum_{j=1}^{q} P(x)\log_2(P(x)) \tag{6}$$

where, q is the number of the process route.

The objective of optimization for production line layout planning is F:

$$F = \begin{cases} \min(C) \\ \min(H_{cms}) \end{cases} \tag{7}$$

The optimization model can be used to solve the system layout with the least cost of logistics and the least complexity of material distribution.

IV. Case Study

This case study is related to an automatic transmission production company. In the company, there is a production line which is responsible for the production process of multiple parts.

A. The Sample

Some major components of the 6-speed automatic transmission are produced in the production line. Different components have their own process route. The distance matrix of machines is shown in Table I. A part of process routes and process allocation is as shown in Table II.

TABLE I
The Distance Matrix of Machines

Location \ Location	1	2	3	4	5	6	7	8	9	10
1	0									
2	3	0								
3	6	3	0							
4	9	6	3	0						
5	12	9	6	3	0					
6	15	12	9	6	3	0				
7	18	15	12	9	6	3	0			
8	21	18	15	12	9	6	3	0		
9	24	21	18	15	12	9	6	3	0	
10	27	24	21	18	15	12	9	6	3	0
…	…	…	…	…	…	…	…	…	…	…
24	5	8	11	14	17	20	23	26	29	22

B. Calculations of the Sample

The layout scheme is calculated by the production line layout planning model based on configuration complexity measurement in Section III. The result is shown in Fig. 3. It can be easier to observe the location of machines. The works in process will be distributed around the loop of the production line.

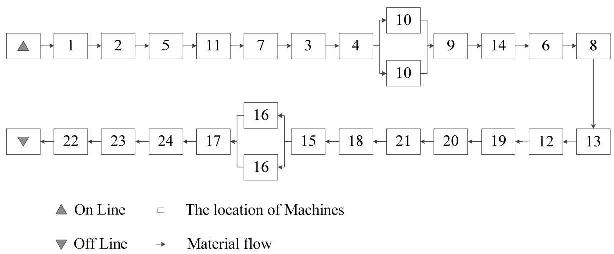

Fig. 3 The optimal layout of the production line

C. Discussion

Production line layout planning is a common research problem in the design stage of manufacturing systems. In most instances, people concentrate on the distribution efficiency and cost which are related to the beneficial result of enterprise directly. The material distribution error and its complexity degree are rarely considered. This study attempts to build an integrated optimization model to calculate the production line layout scheme considering the material distribution cost and distribution complexity. The proposed approach may improve distribution efficiency and reduce distribution errors in the very beginning of the design stage for a common production line layout.

TABLE II
A PART OF PROCESS ROUTES AND PROCESS ALLOCATION

Parts \ Machines	Machine 1	Machine 2	Machine 3	Machine 4	…	Machine *j*	…	Machine 20
Part 1	1,4	2	3,9	5,6,7,8		…		
Part 2			1,2	3,4,5		…		
Part 3		3		1,2,4,5		…		
Part 4	3,4,5		1	6		…		
Part 5	2,3	5,6						
Part 6			4,5	2,3				
Part 7	5,6			2,3,4,10				
Part 8	3,4		5,6,7,8	1,2				
Part 9		3	1,2	4,5				
Part 10				1,2,3,4				
…								
Part *i*	…	…	…	…		…		…
…								
Part 23	6		4					10
Part 24	5,6		2,3	1				

V. CONCLUSION AND FUTURE WORK

An integrated optimization model for production line layout planning has been proposed to improve the material distribution efficiency and success rate. The approach is based on complexity measurement to depict the complexity degree of the material distribution which is related to the success rate of the distribution. The proposed method was validated in a case study on the data provided by an automatic transmission production company. The fine layout planning result shows a practical scheme of the production line.

For future research, the line balancing and scheduling should be incorporated with the layout planning approach which was proposed in this paper.

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