Optimization of Pressure Vessel Manufacturing Shop Layout Based on Genetic Algorithm

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Abstract. For the layout of manufacturing workshop facilities, it is necessary to consider not only the material flow and production efficiency, but also the production safety. In this paper, we use the systematic layout design method to solve the problems in the existing workshop layout design by taking the layout of pressure vessel manufacturing workshop of Company J as an example. In this paper, a genetic algorithm is used to solve the functional area layout optimisation problem of the workshop. The functional area layout problem of the workshop is regarded as a mathematical optimisation problem, and the layout problem is solved by applying mathematical methods after obtaining the integrated relationship diagrams of different functional areas, instead of the traditional manual adjustment methods. This reduces to a certain extent the layout uncertainty of combining qualitative and quantitative analysis, and constructs a model with the maximum arithmetic product of the integrated relationship and adjacency as the objective function by combining the relevant constraints, and the idea of optimization is to increase the area of the bottleneck work station and less area of the redundant space. The evaluation results show that the optimized solution improves the safety, production flexibility and productivity of the shop.

Keywords: pressure vessel workshop · mathematical optimization · genetic algorithm · workshop layout

1 Introduction

Shop floor layout methods are an important research area in industrial engineering, which aims to improve the efficiency and utilization of plant layouts. As industry continues to evolve, the study of shop floor layout methods has changed considerably. The development of shop floor layout methods can be traced back to the 1950s, when Beethoven, an American management scientist, began to study how to make shop floor layouts more efficient to meet the needs of industrial production. He proposed a space-based shop layout scheme that takes physical elements such as paths and locations into account to organize work cells into an efficient layout. In the 1960s, the shop layout approach took a new turn when Max Beaver from Connecticut, USA, introduced computer technology

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into the shop layout scheme. In the 1970s, William Forrest, a British engineer and scientist, proposed a systems-based approach to shop layout, known as the "Shop Layout Method", which is based on a computer system that simulates the actual situation in a factory and can measure the impact of different layouts on production. The Forrester Computer Method is a system-based approach to shop floor layout. In the 1990s, American researcher Corey Carter proposed the "Carter Layout" method, which combines computer technology with traditional spatial layout methods to find the best layout for the shop floor. Carter layout can simulate different layout options and consider several factors at the same time to find the best layout.

From the 1950s to the 1990s, the development of shop floor layout methods has undergone many changes. From the original Beethoven layout to the Beaver computer method, as well as the Forrest computer method and the Carter layout, the study of shop floor layout methods has received more and more attention and has made great progress. Nowadays, research on shop floor layout methods is constantly evolving to meet the changing needs of industrial production.

2 Review of Shop Floor Equipment Layout Studies

Zhang et al. proposed a conceptual framework for an intelligent manufacturing system based on the concept of Industry 4.0, and analyzed the feasibility of applying key technologies such as intelligent processing, intelligent scheduling and intelligent control in the production shop, with the intention of promoting the development of Industry 4.0 [1]; Kato constructed a framework for monitoring workshop production process information based on IoT technology, and used macro programs and industrial kanban technology to realize the machine shop of real-time monitoring [2].

With the rapid development of computer technology, it has promoted the transformation and upgrading of China's manufacturing workshops to information management, but there are still many shortcomings. Yuan Yiyan established a tube manufacturing process status data management system based on the production process of ship tube processing workshop to realize effective management of tube manufacturing process [3]; Qi Baoyun et al. discussed the construction and implementation of workshop MES based on the concept of digital workshop and explained how to build a digital workshop system integration system with MES as the core [4]; Li Lin established a TRIBON-based system based on tube design and manufacturing data requirements established a TRIBON-based tube database and realized the import, extraction and query functions of tube-related information [5]; Gao Huan et al. collected data of discrete workshop production activities based on RF technology and constructed a real-time monitoring system of workshop material production process, which improved the effectiveness and traceability of workshop material production status information [6]; Liu Yifan, based on UG secondary development technology developed a process information model and applied it to the assembly workshop, which improved the assembly efficiency of the workshop [7]; Meng Lili et al. established a workshop management system based on WebServices for the needs of workshop production management, which realized the integration of workshop production site data information and guided the actual production of the workshop [8]; Sun Yanhui based on AES and MD5 algorithm for the digital workshop transmission of The data is encrypted based on AES and MD5 algorithm to avoid data tampering and improve the security of data in the workshop information management system [9]; Yuan Zhikun et al. constructed a pipe processing information management system through information technology, from which pipe processing information is extracted and grouped using grouping technology [10]; Wang Linkun et al. proposed a multidimensional model and analyzed the core elements of the model in detail, which gave an effective solution to solve the manufacturing equipment information integration an effective solution to the problem of manufacturing equipment information integration [11].

The System Layout Planning (SLP) method has a strong practical application with standardised system design procedures and rigorous system analysis techniques. However, the SLP method is not very quantitative and can be influenced by subjective factors of layout planners, with different layout results obtained by different planners, resulting in low accuracy. Therefore, this paper attempts to improve the SLP method to replace the traditional manual adjustment method for quantifying the functional area layout problem.

3 Genetic Algorithm Principle and Process

The genetic algorithm, proposed by John Holland in the United States in the 1970s, is a computational model of the biological evolutionary process that simulates the natural selection and genetics mechanisms of Darwinian biological evolution and searches for the optimal solution by simulating the natural evolutionary process [12]. The algorithm converts the problem sought into a chromosomal genetic problem of biological evolution, usually accompanied by selection, crossover, and mutation processes, by mathematical means and using simulation software. Genetic algorithms are often applied by researchers in the fields of combinatorial optimization and machine learning, as they can obtain better optimization results faster and easier by the designed algorithm when solving complex combinatorial optimization problems [13]. Based on these characteristics, a genetic algorithm was designed to optimize the layout of the pipe processing plant.

The genetic algorithm uses the law of biological evolution, "survival of the fittest", to represent the object of study as a tandem code, forming a genetic code in genetics, and selects individuals in a directional manner through replication, crossover and mutation. Individuals, i.e., the optimal solution to the problem, in the following steps.

(1) Chromosome coding. In the application of genetic algorithm, the variables in the studied problem need to be transformed into corresponding codes, and different coding methods affect the optimization speed and results. The coding methods are usually used in binary coding, Gray code coding and real number coding, etc. The corresponding coding methods are selected for different problem studies.
(2) Determine the initial population. Generally, the initial population can be randomly generated as the initial solution, or the initial population can be customized. The quantity and quality of the initial population affect the optimization speed and results. Too much quantity will lead to too long solution time and affect the evolutionary direction, while too little quantity and too poor quality will affect the solution accuracy, so the appropriate population should be selected.

(3) Calculate the degree of adaptation. The value of fitness function is an important basis for judging the merits of newly generated individuals. According to the research object, the suitable fitness function is established, and the fitness function value represents the strength of hereditary ability of a certain chromosome in the population, and the strong hereditary ability can evolve smoothly to the next generation, and the superior gene will be inherited from generation to generation, and so on, and finally get the optimal solution.
(4) Selection operation. The selection operation is to inherit the individuals with strong adaptive ability in the population directly to the next generation or pairwise crossover to produce new individuals, while the poorly adapted ones are eliminated [14].
(5) Crossover operation. Crossover operation is to replace and recombine two chromosomes in the population to form new chromosomes according to certain rules to improve the search ability, while avoiding premature convergence due to the rapid elimination of chromosomes with poor adaptive ability, which can affect the optimization results [15].
(6) Crossover operation. Crossover operation is to change the genes on the locus of some individuals in the population to get new individuals and improve the population diversity [16].

4 Mathematical Model of the Layout of the Workshop Facilities

4.1 Mathematical Model of Functional Area Layout Problem

In this paper, according to the principle of close arrangement of functional areas with high comprehensive relationship, the model is solved by genetic algorithm and a layout optimization model is constructed. Based on this objective, the workshop functional area layout planning is mainly done through the coordination of each functional area to complete the logistics operations, and the coordinates of the functional area layout are schematically shown in Fig. 1.

Based on these assumptions, the maximum arithmetic product of the integrated relationship and the adjacency correlation is taken as the objective function in this paper. This objective function is given by the following equation.

$$\max F(x) = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} T_{ij} b_{ij} \tag{1}$$

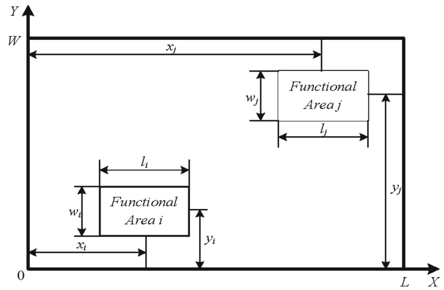

Fig. 1. Schematic diagram of coordinates of functional area layout

Table 1. Adjacency quantification table for functional areas

d_{ij}	b_{ij}
$[0, d_{\max}/6)$	1.0
$[d_{\max}/6, d_{\max}/3)$	0.8
$[d_{\max}/3, d_{\max}/2)$	0.6
$[d_{\max}/2, 2d_{\max}/3)$	0.4
$[2d_{\max}/3, 5d_{\max}/6)$	0.2
$[5d_{\max}/6, d_{\max})$	0.0

where i and j are the functional area numbers, $i \neq j$. n is the number of functional areas. d_{ij} represents the Manhattan distance between i and j by the conversion of d_{ij}, b_{ij} represents the adjacency (proximity between functional areas) between i and j, and $d_{ij} = |x_i - x_j| + |y_i - y_j|$. The values of b_{ij} are shown in Table 1.

Referring to the schematic diagram in Fig. 1 and the assumptions of the model, the constraints of the model are presented in the following equation.

$$|x_i - x_j| \geq \frac{l_i + l_j}{2}, i = 1, 2, 3...7; j = 2, 3, 4...8 \tag{2}$$

$$|y_i - y_j| \geq \frac{b_i + b_j}{2}, i = 1, 2, 3...7; j = 2, 3, 4...8 \tag{3}$$

$$\frac{l_i}{2} \leq x_i \leq L - \frac{l_i}{2}, i = 1, 2...8 \tag{4}$$

$$\frac{w_i}{2} \leq y_i \leq W - \frac{w_i}{2}, i = 1, 2...8 \tag{5}$$

$$1/4 \leq \lambda_i \leq 4 \tag{6}$$

Equations (2) and (3) ensure that there is no overlap between the functional areas, Eqs. (4) and (5) ensure that the functional areas do not extend beyond the rectangular presentation area and Eq. (6) defines the range of aspect ratios.

4.2 Genetic Algorithm Design for Functional Area Layout

4.2.1 Coding Representation of the Solution

The result of the optimisation of the chromosome decoding is made up of the number of functional regions and the numbers "0" and "-1". The "0" means that it will produce a new layer, while the "-1" is intended to increase the diversity of the layout optimisation, with the functional regions at either end of the "-1" being juxtaposed. For example, the layout diagram corresponding to the results (7 5 1 0 8 3 -1 4 0 6 2) is shown in Fig. 2. In this paper, a sequential coding method is used, whereby the functional areas are ordered according to their numbering. With this coding method, each scheme corresponding

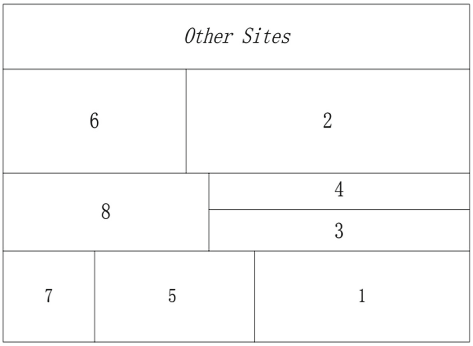

Fig. 2. Decoding diagram of optimization results

to a layout solution will be obtained by the numbering of the functional areas and the number of layers. First, the entire functional area is divided into layers according to the layer number. The functional areas are then arranged from left to right according to their coding order.

4.2.2 Design of the Function

The genetic algorithm cannot deal with constraints directly, so a penalty function is introduced, which consists of a penalty coefficient and a penalty term, in order to transform the constrained problem into an unconstrained one. "M" represents a very high penalty coefficient (in this paper M = 10000) and "*publish*" represents the number of functional areas that cannot satisfy the requirements (aspect ratio). The penalty function is denoted by $M * publish$.

Provided that the fitness function is greater than zero, the penalty function is passed so that the objective function with the maximum arithmetic product is converted to an objective function with the minimum arithmetic product.

At the same time, in order to improve the evolutionary competition, a high coefficient "P" should be introduced to appropriately increase the fitness of individuals in order to increase the diversity between the best individual fitness and the other individuals. In this paper, P = 100 is used. Therefore, the objective function is converted to the following equation.

$$E(x) = p * \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(\max\left|T_{ij}\right| + 1 - T_{ij}b_{ij}\right) + M * publish \tag{7}$$

Using the inverse method to calibrate the function, the following equation is obtained [8].

$$Fit(x) = 1/E(x) \tag{8}$$

5 Genetic Operator Operation

In this paper, the selection strategy is a proportional selection strategy, called roulette wheel selection. Roulette wheel selection is a random sampling method. Here, some parameters are defined in this paper. nP is the population size, X_i^k represents the individual i in the kth generation, and E_i^k is the fitness of X_i^k. The probability of an individual being selected into the next generation is $p_i = E_i^k / \sum_{i=1}^{NP} E_i^k$.

Assuming $p_0 = 0$, the procedure for election by proportion is as follows. First, it generates θ, which is a uniformly distributed random number from 0 to 1. If $\sum_{j=0}^{i-1} p_j \leq \theta \leq \sum_{j=0}^{i} p_j$, the individual X_i^k will be elected next and become the parent of k + 1 generations. The above steps are repeated without stopping until the parental NP is selected [11].

6 Algorithm Simulation

In this paper, after analyzing the logistical and non-logistical relationships between the different functional areas, the SLP method is used to quantify the levels of logistical and non-logistical relationships as a function of equipment types and workflow in the company's pressure vessel manufacturing plant. The comprehensive relationship of each functional area is obtained by weighting method. In this paper, we choose 3:1 as the weight of logistics and non-logistics relationship, then the integrated relationship score between functional areas A_i and A_j can be calculated by $TR_{ij} = 0.75MR_{ij} + 0.25NR_{ij}$. The integrated relationship scores are shown in Table 2.

In Table 2, A~H represent the batching area, mixing area, forming area, drying area, processing area, shelling area, sintering area and flaw detection area respectively, as shown in Table 3.

Analysis of the computational results of the genetic algorithm.

Table 2. Integrated relationship scores between functional areas

Areas	A	B	C	D	E	F	G	H
A	0	3.5	1.75	-0.25	2	-0.25	-0.25	0
B	3.5	0	3	0.75	1	0	0	0
C	1.75	3	0	0.5	1	0	0	0
D	-0.25	0.75	0.5	0	0	1	1	0.5
E	2	1	1	0	0	0	0	0
F	-0.25	0	0	1	0	0	1	0.25
G	-0.25	0	0	1	0	1	0	0.75
H	0	0	0	0.5	0	0.25	0.75	0

Table 3. Area of each functional area

Number	Operation	Site specifications	Size(m2)
1	Batching area	45x14	630
2	Kneading area	49x14	686
3	Forming area	45x14	630
4	Drying area	27x20	540
5	Processing Zone	45x20	900
6	Shelling area	49x14	686
7	Sintering area	57x14	798
8	Flaw Detection Zone	63x14	882

In this paper, the model is solved, and the values corresponding to the parameters of the transmission algorithm are shown in Table 4.

In this paper, 10 random operations were performed in order to solve practical situations. The computational results are given in Table 5.

Assume that objmax is the maximum value of the objective function, objmax = 23.45. xv is the result of decoding the functional regions, xv = (5 3 8 0 2 4 6 7 0 1),ans = 0. We choose the calculated sequence with the largest value of the objective function (23,45).The number of evolutions with the optimal function value curve is obtained as shown in Fig. 3.

The evolutionary process is illustrated in Fig. 4, where the horizontal and vertical axes represent the evolutionary iterations and the current optimal evaluation value, respectively, and the number of evolutionary iterations with the optimal function value curve is obtained as shown below. Based on the above results, the functional area layout of the workshop can be obtained, and the workshop layout after performing decoding is shown in Fig. 4. In this scheme, the interference between each other is low, and the

Table 4. Parameter values

Parameter	Meaning of parameters	Value of the parameter
NG	Iteration time	40
NP	Population size	60
pc	Crossover probability	0.9
pm	Mutation probability	0.1
k	Number of gene exchanges in mutations	1
P	Target penalty coefficient.	100
M	Penalty coefficient	10000

Table 5. Computational results of the genetic algorithm

Evaluation order	Best evaluated value	Original objective function	Release value
1	19805	22.45	0
2	20015	20.35	0
3	19705	23.45	0
4	19730	23.2	0
5	20060	19.9	0
6	19805	22.45	0
7	20015	20.35	0
8	19705	23.45	0
9	19730	23.2	0
10	20060	19.9	0

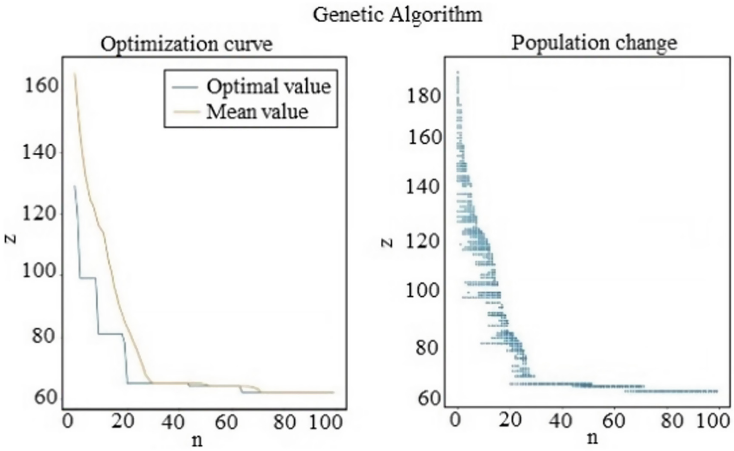

Fig. 3. Optimal function value curve

functional areas of the production area are closely arranged, which shortens the logistics operation time and improves the production efficiency.

In order to verify the validity of the proposed model, the original, SLP and SLP-GA schemes are compared, and the comparison of the before and after optimization schemes is shown in Table 6. The optimized layout is significantly lower in terms of objective function value and logistics cost.

In summary, the layout scheme obtained by the genetic algorithm designed and solved in this paper is reasonable.

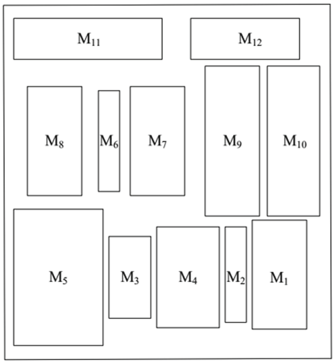

Fig. 4. SLP-GA method workshop layout

Table 6. Comparison of before and after optimization scheme

Layout scheme	Objective function value	Logistics cost
Original Solution	2746	4158
SLP Solution	2185	3564
SLP-GA scheme	1952	3253
Final optimization effect/%	28.9	21.7

7 Summary

In this paper, we studied the layout optimization of the pressure vessel workshop of Company J. The current problems of the workshop layout were sorted out from several aspects, then the current situation of the layout of the pressure vessel workshop of Company J was analyzed by using the SLP method, according to which a mathematical model based on the genetic algorithm was constructed and solved, and finally a new layout scheme was obtained, and the feasibility of the new scheme was verified by simulation.

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