IOP Conference Series: Materials Science and Engineering

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To cite this article: Huang Zhigang *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **692** 012023

IOP Conf. Series: Materials Science and Engineering **692** (2019) 012023 doi:10.1088/1757-899X/692/1/012023

Design Method of Engine Room Equipment Layout Based on Improved Fuzzy Comprehensive Evaluation

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Abstract. Engine room is the place where marine power equipments, pipelines and other equipments are arranged centrally. In order to optimize the design process of engine room equipment layout, this paper proposes a method for the optimization design of engine room layout baesd on improved fuzzy comprehensive evaluation. By constructing the personnel activity space model and equipment space model, formulating the engine room environment constraint conditions dominated by personnel experience factors and obtaining the feasible scheme of engine room equipment layout. By designing the evaluation model of equipment layout plan in the engine room, formulating the evaluation method dominated by fuzzy comprehensive evaluation algorithm and obtaining the optimal layout scheme. Based on fuzzy comprehensive evaluation method, the improved method directly retains the influence of the design experience factors of personnel, which can make engine room equipment layout and pipelines more in line with engineering requirements, as well as provide better equipment accessibility and personnel accessibility.

1. Introduction

Nowadays, the research on ship engine room layout is developing towards intellectualization [1]. Lee K H adopted artificial intelligence technology to optimize the layout of ship engine room [2]. Jin Hyung developed the unit generation method to automatically process the piping design of ship engine room [3]. Zhang used the genetic algorithm to optimize the layout of key equipments and carried out the 3D layout of engine room [4]. Various literatures mainly focus on the intelligent ship layout algorithm. They would like to use the algorithm model and 3D modeling to optimize the layout of the equipments in the ship's living room or the pipelines in engine room. However, excessive reliance on algorithms will weaken the designer's experience factor. At the same time, some valuable intelligent layout models only consider the living room, whose environment is greatly different from engine room. Therefore, it is necessary to redesign the layout model for the engine room environment.

In order to overcome these shortcomings, this paper designs a fuzzy comprehensive evaluation method. Compared with the algorithm-oriented design idea, this method takes the engine room environment constraint condition as the evaluation index before the algorithm evaluation, and directly exerts the influence of design experience factors on the scheme, so that the engine room equipment layout scheme is more in line with the actual needs. Compared with other evaluation index models, the evaluation index model developed by the invention focuses on the special environment of the engine room, making the algorithm more fit the requirements of engine room equipment layout, and has certain pertinence.

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2. Design of engine room environmental constraint condition

Engine room environmental constraint condition refers to the state conditions that must or should be satisfied during equipment layout, including equipment level, location space, space model type and restrict indexes. On the basis of analyzing personnel activity space model, building equipment space model by the design experience of personnel, and determining the constraint conditions of engine room environment to obtain feasible layout schemes.

2.1. Personnel activity space model

Considering the personnel channel requirements and setting personnel attributes. Setting the standard figure of male is 1.78m, the shoulder width is about 440mm, the side width is about 210mm, and the arm length plus hand length are 680mm.

In terms of height, the main equipment layout area in engine room is between the steel plate and the upper deck. It is set that the minimum height for personnel to keep walking upright is 1.8m and the range of 0 ~1.8m from the steel plate is regarded as the personnel activity space. If the height of a certain area is lower than 1.8m, people need to bend down. If the height is lower than 1.6m, people need to squat down.

In terms of width, we take a shoulder width of 660mm as the minimum width of main evacuation passageway, and take a side width plus arm length of 680mm as the minimum width of maintainable space.

In addition, defining the main pipeline space area as the space above the height of 1.8m from the steel plate, which only affects the equipment layout. The restricted pipeline space is defined as the range of 1.6~1.8m height from the steel plate, which has an impact on equipment layouts and personnel activities.

The dimension table of personnel activity space model is shown in table 1:

Table 1. Dimension table of personnel activity space model.

Personnel activity space model area		Height\Width
High space	Minimum height of person walks upright	1.8m
	Stoop walking height area	1.6~1.8m
	Crouch walking height area	Less than1.6m
Width space	Minimum width of main evacuation passageway	660mm
	Minimum maintainable space width	680mm
Pipeline space	Main pipeline space area	Higher than 1.8m
	Restricted pipeline space area	Higher than 1.8m

2.2. Equipment space model

(1) Unit space:

Unit space [5] is an envelope of equipment model, which is created according to the inherent properties of the device model.

(2) Pipe coverage space:

Defining the unit space of pipeline and its vertical downward space area as pipeline coverage space, where is not recommended to place equipments in order to avoid putting influence on personnel passage and maintenance work.

(3) Free space:

Equipment accessibility refers to the state in which the maintenance personnel can see the equipment and carry out maintenance operation during maintenance [6]. The space which is set aside for equipment maintenance in the initial design stage is called free space, which expresses the maintenance operation space.

The modeling process of free space is as follows: Analyzing the accessibility requirements of equipment, determing the size of space allowance, and assigning scope "base" to the equipment unit space. The "base" represents the size of the surrounding operating space, which is called free space allowance. There will be superimposed areas in the free space. The superimposed area is also regarded as a free space that satisfies the conditions and does not constitute interference with each other.

(4) Channel space

The space which is set aside for personnel activities in the initial design stage is called channel space, which expresses the main activity area and evacuation area. The channel space in engine room is mainly arranged around the main engines, gear boxs, pedals, generator sets and main switchboards, as well as in front of escape doors and escape straight ladder passages.

The process of channel space modeling is the same as free space modeling. Defining minimum width of main evacuation passageway of 660mm as channel space allowance. The overlapping channel space also satisfies the conditions and does not constitute interference with each other.

2.3. Engine room environment constraint conditions

Using personnel activity space model and equipment space model. Then according to three principles of "First master, then auxiliary. First large, then small. First heavy, then light" to grade engine room equipments [7]. Building the engine room environment constraint conditions table as shown in table 2:

Table 2. Table of equipment constraint conditions.

Equipment level	Equipment name	location space	space model	restrict indexes
Level-1 equipment	Main engine, main engine exhaust silencer	Bottom structure layer	Free space model	No interference Balance of center of gravity Spare room for gear boxes and pedals
	Door, straight escape	Personnel activity space area	Free space model	Near the main personnel corridor Follow the engine room environment
Level-2 equipemnt	Seawater filter, Sea chest, seawater pipeline	Bottom structure layer	Pipeline space model	Sea chest should avoid midship station Pipe coverage space is minimal Equipments must not be layouted above sea water piping
	Engine inlet and exhaust ducts	Pipeline coverage space area	Pipeline space model	No interference Pipe coverage space is minimal Try not to layout equipments under pipelines
Level-3 equipment	Main engine and auxiliary engine start the battery	Personnel activity space area	Unit space model	No interference layout around the main engine As far as possible layout in the free space, the main channel and pipe space outside

3. Design of fuzzy comprehensive evaluation method for engine room equipment layout

Using fuzzy mathematics theory and statistics principle to evaluate the comprehensive of engine room layout. Under the expert evaluation foundation, using the linear weighted method to assign rating labels for each objective function of multi-objective optimization problem. Then, multipling rating labels and weight coefficient of this objective function to get fuzzy comprehensive evaluation value so as to transform the multi-objective problem into a single-objective problem. Now the optimal solution of single objective problem is an effective solution of multi-objective optimization problem.

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3.1. Analysis of engine room layout evaluation index

The evaluation of the layout of engine room is based on the evaluation value of each factor. Starting from the equipment constraint conditions and setting the evaluation model of engine room layout scheme, as shown in figure 1:

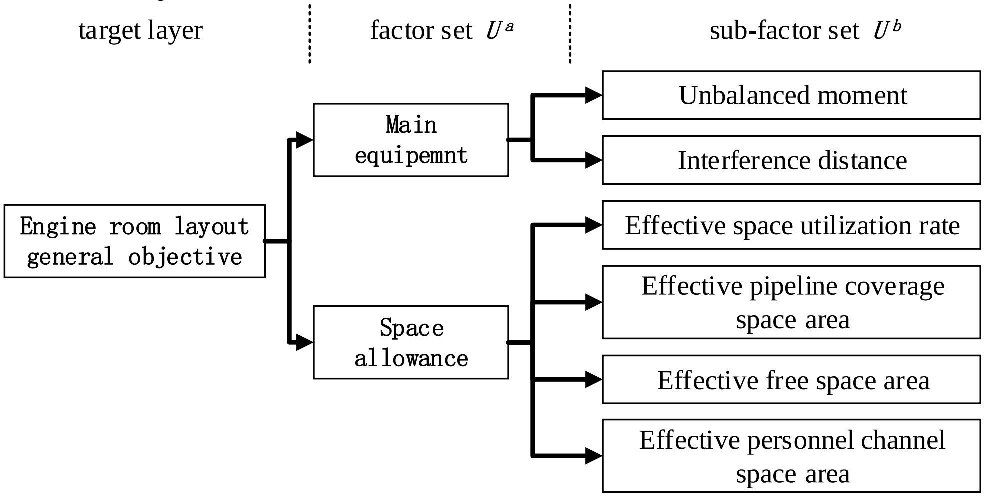

Figure 1. Evaluation model of engine room layout scheme.

The evaluation indexes of sub-factor set are shown in the following:

(1) The unbalanced moment M is the minimum

In order to avoid the ship's lateral inclination and to ensure the strength of each deck platform, equipments should be arranged in such a way that the absolute value M of the algebraic sum of moments in the middle distance section is as small as possible.

$$M = \left| \sum_1^n m_i y_i \right| \tag{1}$$

Where m_i is the weight of equipment i. y_i is the horizontal coordinate of center of mass of equipment i, and n is the total number of equipments.

(2) The interference distance f_1 is the largest

For the sake of operational safety, a certain distance should be kept between equipments in engine room. The larger the interference distance f_1 between equipment, the better.

$$f_1 = \sum_{i=1,j=1}^q \left| X_i - X_j \right| \tag{2}$$

Where q is the total number of equipments requiring interference distance. X_i and X_j are the location parameters of equipments requiring interference distance.

(3) The effective space utilization rate E is the largest

Increasing the effective space utilization rate E of engine room can facilitate the personnel maintenance activities in engine room. Since the equipments cannot be reduced, the larger the effective space utilization rate E is, the better it will be for the work.

$$E = 1 - \frac{\sum_{i=1}^{n} S_i^1 + \sum_{j=1}^{m} S_i^2}{A} \tag{3}$$

Where S_i^1 is the space area of engine room occupied by equipments. S_j^2 is the area of engine room corners (invalid space) that cannot be utilized. i is the equipment number. The value of E is between 0 and 1, and the larger the value is, the higher the effective space utilization is [8].

(4) The effective pipeline coverage space area S_1 is the minimum

$$S_1 = \sum_{i=1}^{n} S_i^1 - \sum_{j=1}^{m} S_j^2 \tag{4}$$

Where S_i^1 is the pipeline coverage space of pipeline i. S_j^2 is the pipeline coverage space overlap area of pipelines j.

(5) The effective free space area S_2 is the largest

$$S_2 = \sum_{i=1}^{n} S_i^1 - \sum_{j=1}^{m} S_j^2 \tag{5}$$

Where S_i^1 is the free space area of equipment i. S_j^2 is the free space overlap area of equipments j.

(6) The effective channel space area S_3 is the largest

$$S_3 = \sum_{i=1}^{n} S_i^1 - \sum_{j=1}^{m} S_j^2 \tag{6}$$

Where S_i^1 is the channel space area of equipment i. S_j^2 is the channel space overlapping area of equipments j.

3.2. Establish weight coefficient evaluation index

Constructing pairwise comparison matrix of factors u_1, u_2..., u_n from factor set U^a and sub-factor set U^b to obtaine the importance index weight matrix [9]. Then, solving the characteristic roots respectively, and obtained the relative weight ω_i of each index under a single criterion after normalization.

Assuming the weight of factor i in U^a be ω_i^a , then the U^a weighted set is [10] :

$$A = \{\omega_1^a, \omega_2^a, ..., \omega_i^a, ..., \omega_m^a\} \tag{7}$$

Where m is the total number of evaluation indexes of factor set.

Assuming the weight of factor j in U^b is ω_{ij}^b , then the U^b weighted set is:

$$B_i = \{\omega_{i1}^b, \omega_{i2}^b, ..., \omega_{ij}^b, ..., \omega_{im}^b\} \tag{8}$$

Where i represents the sub-factor set under the i U^a, and m is the total number of evaluation indexes of sub-factor set.

3.3. Design fuzzy comprehensive evaluation set

Due to the nature of evaluation indexes and the units of measurements are different, there is often a lack of correlation between indexes. In order to avoid evaluation failure, establishing a expert team and providing effective evaluation set. Each evaluator makes an evaluation conclusion for each factor (that is, for a certain element in the evaluation set), and then calculates the percentage of various evaluation conclusions to obtain the membership degree S_i. Membership degree S_i constitute a single factor evaluation set r:

$$r = [S_1, S_2, S_3, ..., S_m]^T \tag{9}$$

Where m represents the total number of evaluation results.

single factor evaluation set r_i constitute a single factor evaluation matrix R_i:

$$R_i = [r_1, r_2, r_3, ..., r_n]^T \tag{10}$$

Where n is the total number of evaluation indexes of a sub-factor set.

The sub-factor weighted set B_i is introduced to calculate the first-level fuzzy comprehensive evaluation set C_i of factors i:

$$C_i = B_i \times R_i \tag{11}$$

Where C_i is the fuzzy comprehensive evaluation of factor set i [11][12]. The larger the C_i value is, the better the effect of factor set i is.

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C_i only reflects the unilateral evaluation value, so the factor set weighted set A is introduced to calculate the second-level fuzzy comprehensive evaluation set:

$$D = A \times [C_i]^T \tag{12}$$

Where $[C_i]$ is the second-level single factor evaluation matrix. D represents the evaluation value of target layer, namely the scheme evaluation value. The larger the value of D, the better the effect of the scheme.

4. Method of equipment layout in engine room

Combined with personnel design experience factors and fuzzy comprehensive evaluation algorithm to guide the layout of equipment in engine room, constructing a method flow of equipment layout in engine room as is shown in figure 2:

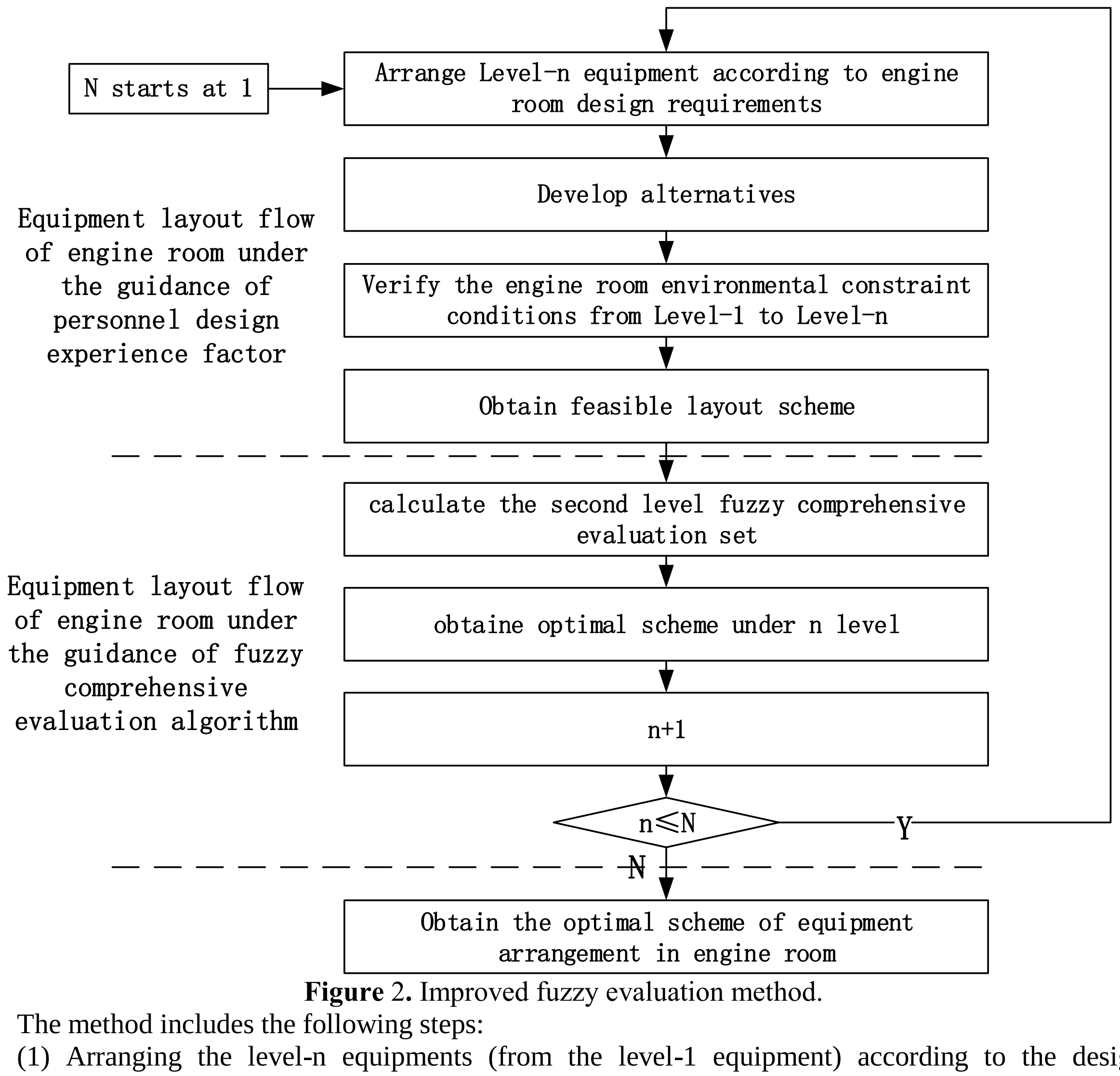


Figure 2. Improved fuzzy evaluation method.

The method includes the following steps:

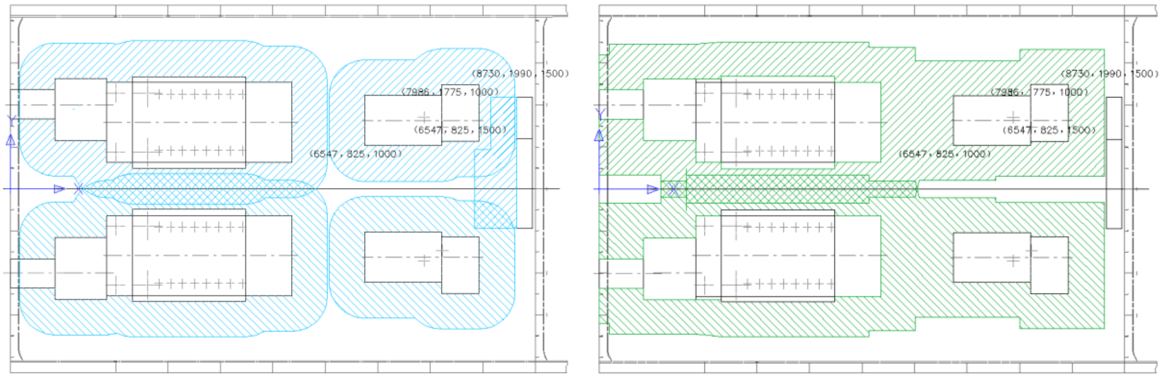
(1) Arranging the level-n equipments (from the level-1 equipment) according to the design requirements of engine room. Adjusting the position of equipment based on the design experience of personnel, and form 3 to 4 alternative schemes;

(2) Verifing the engine room environmental constraint conditions of each scheme from grade 1 to n, and obtaining the feasible layout scheme which meets the conditions. If n=1, only verifing the engine room environmental constraint conditions of current level.

(3) Using the fuzzy comprehensive evaluation algorithm to evaluate the feasible layout scheme, and obtaining the second-level comprehensive evaluation set D. Retaining the best scheme, namely the scheme with the maximum D.

(4) Cycling (1) and (3) until n= N (the toatal number of quipement levels) , and end the cycle. At this time, all equipments are arranged, and the scheme with the maximum D value is retained, that is, the best scheme.

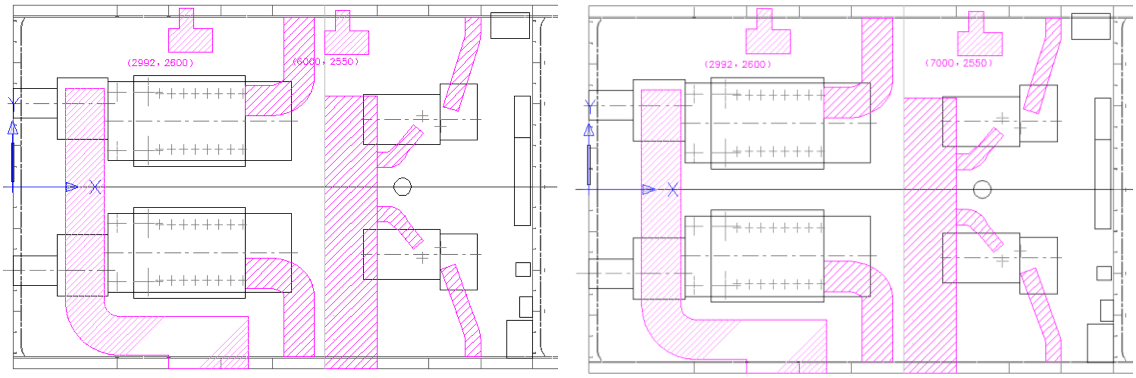
For example, when level-1 equipments satisfy constraint conditions, we design multiple feasible schemes. Checking the space constraint conditions of a scheme, the effect as shown in figure 3 can be obtained:



(a) check graph of free space (b) check graph of personnel space

Figure 3. Equipment free space diagram.

Optimizing engine room equipment layout of a certain ship. The level-2 feasible scheme layouts are shown in figure 4. Where, compared with scheme A, scheme B moves 200cm towards the bow of the generator set:



(a) scheme layout of scheme A (b) scheme layout of scheme B

Figure 4. Schemes of three-level equipment layout.

Obtaining the optimal target layer evaluation value D under scheme A is 0.79. Compared with the optimal target layer evaluation value D under scheme B is 0.81. Selecting the evaluation value of 0.81 to retain the optimal scheme B.

5. Conclusion

Aiming at the problem of engine room equipment layout, this paper puts forward a method of engine room equipment layout optimization design with more engineering practice value. This method considers the influence factors of personnel experience and puts forward the preliminary equipment layout scheme according to the engine room environmental constraint conditions. Then through the fuzzy comprehensive evaluation indexes to accomplish the algorithm level of the pros and cons of scheme comparison to obtain the optimal scheme. This method increases the influence of human decision on the basis of algorithm evaluation, conforms to the design specification and avoids subjective speculation, as well as ensures the scientific analysis and comprehensive measurement of the equipment layout in engine room.

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