Modelling and Simulation of Facility Planning Problem Based on Improved SLP Method

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Abstract. Facility planning plays a critical role in various fields. An excellent facility layout can minimize the losses caused by the connection between facility units in production operations. In this paper, we improved the traditional Systematic Layout Planning (SLP) method, combine it with the multi-objective decision optimization model. The Improved SLP (ISLP) method is described in detail in this paper, including its principles, process of building model, and calculation methods. To make the ISLP more suitable for research and practical problems, we established a mathematical model for it. This optimization model was also applied to the existing facility layout problem to realistically validate the effectiveness of the ISLP and the model. Results on the established model were found first, then the Flexsim simulation software was used to simulate the layout of the facility before and after the improvement. Finally, the results of the experiment were analysed and compared.

1. Introduction
Facility planning plays an increasingly significant role in all walks of life applications, for instance, from assembly line processing factory, logistics sorting centre, experimental base, testing centre, etc., to kitchen layout even. The research content of facility planning mainly focuses on the layout planning of production or laboratory equipment, so as to reduce the loss or waste caused by the interrelationships among each facilities unit such as handling and transmission. A manufacturing company or factory with a well-designed facility layout can at least reduce operating costs by more than 50% [1]. Therefore, more and more attention has been paid to the study of facility planning.

However, it is not easy to design an excellent facility layout in practical applications, either it is difficult to make sure whether the designed new layout is good enough, or it can't be easily moved the existing design layout to validate new design. Therefore, establishing an optimized model for the facilities to be planned through a systematic approach, finding the optimization result with the related method, and verifying the optimization results with the help of the simulation software are of remarkable research value.

The loop layout is one well known general types of design used in production systems [2], the only downside is that it does not take into account the human factors in the facility planning [3]. Ganesharajah et al. [4] reported and discussed an approach called Automated Guided Vehicle (AGV) system that provides greater flexibility, better space utilization, and lower operating costs, but ignores the connections between non-functional areas. The SLP method was proposed by Muther in 1961 [5], which has pushed the study of facility layout issues from the qualitative research stage to the
quantitative research stage. The chart analysis and the graphical model were used as main technical means, at the same time, a new concept of Mathematically Quantified Relational Levels(MQRL) [5] was defined to describe the logistics relationship and the non-logistics relationship between operations units, where the former is the direct relationship between facility units, such as the flow relationship between the upper and lower links on the assembly line, the latter is the indirect relationship between facility units, such as the influence of units, the connection of functional areas, which achieved a quantitative analysis of the entire process of facility layout and established a quantitative evaluation model of facility layout design.

However, there is a clear defect in the SLP method. It is relatively easy to be affected by the subjective factors of the layout planner when solving the problem of facility layout, correspondingly, the layout plan for the design varies from person to person and varies. And a host of tedious manual adjustments are needed to meet the requirements of actual conditions in practical applications, the workload of manual adjustment is extremely large especially when there are many partitions.

To overcome the foregoing disadvantages, in this paper, we have improved the traditional SLP method, combine it with the Multi-Objective Optimization Model (MOOM) [6][7]. MOOM can connect the logistics relationship and the non-logistics relationship mentioned above, making the algorithm and ISLP simpler without losing any information. We introduced in detail the ISLP and established a mathematical model for it. Moreover, the existing facilities planning was relocated through the ISLP method, the layout of the facilities before and after the improvement were simulated based on the Flexsim simulation software, and the experiment records are compared and analysed to verify the effectiveness of the algorithm and model.

2. Methodology
In the vast majority of facility planning problem, the reason why the logistics relationship and the non-logistics relationship between units and units generally are considered as the main influence and study factors is that the latter already contains all the factors that cannot be directly quantified except for the former that can be quantified [8][9]. This paper also focuses on these two factors as the optimization goal. Based on the combination of the traditional SLP method and the multi-objective decision optimization model, the static layout problem model of the multi-objective optimization system is established, which makes us propose a new method to improve the static facility planning scheme, so as to minimize the defects caused by the traditional SLP method. Only a small amount of unquantifiable optimization goals is directly scored by experts as non-logistic factors, and the scoring results are quantified in conjunction with multi-objective decision algorithms. It not only simplifies the complexity of the model operation, but also ensures the diversity of the static layout of the facility system for the optimization objectives. The following is a step-by-step explanation of the method and its principles.

1) Firstly, the traditional SLP method is still needed to describe and get the non-logistics relationship among the facility units. At the same time, quantify the logistics relationship among each unit to obtain the flow rate table, as shown in the part 1 of figure 1. In this part, input data is critical, including product details, quantity, route planning, service area, time description, which is the basis of everything and requires an amount of argumentation and design to ensure that an excellent design layout can be designed.

2) Secondly, after obtaining the flow rate table and the non-logistics relationship, the mathematical model method completely replaces the manual layout adjustment to quantify non-quantifiable non-logistic factors. And then set up the objective functions of non-logistics relations and the logistics relations respectively, as shown in the part 2 of figure 1.
Figure 1. The ISLP structure diagram.

In figure 1, \( P, Q, R, S, T \) in the part 1 represent the five basic elements of SLP method, product, quantity, route, service, time. The data of the part 1 can be adjusted according to actual demand. The objective function of the part 2 mainly considers the logistics factor and the non-logistics factor in this paper. If the realistic situation is more complicated, the objective function can be increased accordingly, which also applies to the part 3. This paper and diagram only considers the general situation.

3) Finally, some other requirements that need to be met in the facility planning layout are considered to be the constraint and then appear in the model in this way, as shown in the part 3.
The entire mathematical model contains two optimization objectives. The MOOD can be used to solve the optimal layout and find the results. The specific improved SLP method structure diagram is shown in Figure 1.

3. Mathematical Model

3.1. Establish the objective function

In this model, the goal to be achieved is divided into two parts. The first part is the minimization of quantifiable logistics costs, including planning the shortest logistics path and the functional area with large material flow as close as possible. The second part is the maximization of non-quantitative non-logistics parts, maximizing the convenience of personnel contact between different facilities, and achieving the greatest correlation between office area and production operation. We established the following two objective functions.

1) The objective function of the lowest cost of logistics between facility units can be described by the (1).

\[
\text{Min } Z_1 = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} C_{ij} * Q_{ij} * D_{ij}
\] (1)

2) The largest non-logistic relationship value can be described by the (2).

\[
\text{Max } Z_2 = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} * D_{ij}
\] (2)

Where \(i\) and \(j\) are the facility unit numbers, \(N\) is the total number of facility units, \(C_{ij}\) is the unit logistics cost per unit distance of facility units \(i\) to \(j\), \(Q_{ij}\) is the average traffic between facility units \(i\) and \(j\), \(T_{ij}\) is the non-logistic correlation value between facility unit \(i\) and facility unit \(j\), which is determined after comprehensively considering the closeness of the non-logistic relationship between facility unit \(i\) and facility unit \(j\), \(D_{ij}\) is the distance between facility units \(i\) and \(j\) in the facility layout, showing in (3).

\[
D_{ij} = |X_i - X_j| + |Y_i - Y_j|
\] (3)

Where \(X_i, Y_i\) is the coordinate values of facility unit \(i\) in the layout plan of the facility.

3.2. Convert multi-objective optimization decisions to single

The above multi-objectives can be converted into single objective decisions, which is for simplify the target model. Considering the different dimensions of (1) and (2), the unitary factors \(\mu_1\) and \(\mu_2\) are added to unify their dimensions. Meanwhile, the proportion of the two objective functions in the actual application will also be different. Therefore, the weights \(\theta_1\) and \(\theta_2\) are respectively assigned to the objective function, thereby obtaining the single objective function (4).

\[
\text{Min } Z = \mu_1 \theta_1 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} C_{ij} * Q_{ij} * D_{ij} - \mu_2 \theta_2 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} * D_{ij}
\] (4)

\[
\mu_1 = \frac{1}{\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} C_{ij} * Q_{ij} * D}
\] (5)

\[
\mu_2 = \frac{1}{\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij}}
\] (6)

\[
\theta_1 + \theta_2 = 1
\] (7)

Where \(D\) is the sum of the length and width of the general planning area. The weights \(\theta_1\) and \(\theta_2\) depend on the actual application.
3.3. Establish constraints

Whether the SLP method before or after the improvement, it is to better solve practical problems. Therefore, it is critical and necessary to establish the complete constraints according to the requirements of the facility layout.

1) All facility units cannot overlap and there should have a minimum spacing between each two facility units. Get constraint expressions (8), (9).

\[
\begin{align*}
|X_i - X_j| - (L_i + L_j)/2 & \geq D_{X_{ij}} (8) \\
|Y_i - Y_j| - (W_i + W_j)/2 & \geq D_{Y_{ij}} (9)
\end{align*}
\]

Where \( L_i \) is the length of facility unit \( i \), \( W_i \) is the width of the facility unit \( i \), \( D_{X_{ij}} \) is the minimum spacing of facility \( i \) and \( j \) in the \( X \)-axis direction and \( D_{Y_{ij}} \) is the minimum spacing of facility \( i \) and \( j \) in the \( Y \)-axis direction.

2) There shall be a certain distance between the facility unit and the perimeter of the layout range. Get constraint expressions (10), (11).

\[
\begin{align*}
L_i/2 + H_i - X_i & \leq 0 (10) \\
W_i/2 + K_i - Y_i & \leq 0 (11)
\end{align*}
\]

where \( H_i \) is the minimum distance of the facility \( i \) from the boundary in the \( X \)-axis direction and \( K_i \) is the minimum distance of the facility \( i \) from the boundary in the \( Y \)-axis direction.

3) All facility units must be within the layout, which is the size of the facility does not exceed the total length and total width. Get constraint expressions (12), (13).

\[
\begin{align*}
X_i - (H - L_i/2 - H_j) & \leq 0 (12) \\
Y_i - (K - W_i/2 - K_j) & \leq 0 (13)
\end{align*}
\]

Where \( H \) is the total length of the planning area in the \( X \) axis direction and \( K \) represents the total length of the \( Y \)-axis direction.

4) Fixed constraints. Some facility units must be fixed in a certain location. Get constraint expressions (14), (15).

\[
\begin{align*}
X_i^* = X_s (14) \\
Y_i^* = Y_s (15)
\end{align*}
\]

Where \( X_i^* \), \( Y_i^* \) is a specific device unit and \( X_s \), \( Y_s \) is a fixed value.

5) Non-negative constraints. All factors in the facility planning problem are positive.

6) There are other constraints that exist in the actual problem category. This completely depends on the actual problem and the designer.

4. Model Simulation and Evaluation

According to the general model established in part three, it is applied to the planning of a city's logistics sorting centre facilities. First establish a goal decision model. Then, calculate the optimization result in MATLAB, simulate the result within Flexsim software. Finally, compared the experimental results between before and after optimization to validate the model.

4.1. Describe the experimental background

The experimental object selected in this paper is a sorting centre of a large logistics company. The main task is to classify the goods from various places. These goods are sorted and distributed to all corners of the city. Then, from the moment the goods arrive, the shorter the time the goods stay in the sorting centre, the higher the customer satisfaction.
From the time of the goods arrive to the end of sorting, the goods pass through multiple functional areas. Due to the initial shortage of facilities planning and design, the goods have a residence time in each functional area, and there is also a phenomenon of accumulation of goods, and even time-consuming and labour intensive phenomena, such as manual handling.

Therefore, this paper conducts this experiment by collecting field operation data of this sorting centre in the field, including cargo volume, cargo route, function area function and existing facility layout.

4.2. Build a model based on actual problems.

\[
\text{Min } Z_1 = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} C_{ij} * Q_{ij} * D_{ij} + \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} * D_{ij}
\]

\[
\begin{align*}
|X_i - X_j| - (L_i + L_j)/2 &\geq D_{Xij} \\
|Y_i - Y_j| - (W_i + W_j)/2 &\geq D_{Yij} \\
L_i/2 + H_i - X_i &\leq 0 \\
W_i/2 + K_i - Y_i &\leq 0 \\
X_i - (H - L_i/2 - H_i) &\leq 0 \\
Y_i - (K - W_i/2 - K_i) &\leq 0 \\
X_{i*} &= X_s \\
Y_{i*} &= Y_s \\
\mu_1 &= 1/\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} C_{ij} * Q_{ij} * D \\
\mu_2 &= 1/\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} \\
\theta_1 + \theta_2 &= 1 \\
D_{ij} &= |X_i - X_j| + |Y_i - Y_j| \\
X_{ij}, Y_{ij} &\geq 0, \ i, j = 1, ..., N
\end{align*}
\]

Among them \( H, K, C_{ij}, D, D_{Xij}, D_{Yij}, H_i, K_i, \theta_1 \) and \( \theta_2 \) are all known. All data for this experiment was taken from actual sampling.
Figure 2. The result of software simulation using Flexsim

In figure 2. The small blue area is the starting position of the goods, the large black area is the cargo temporary storage area, the black long strip is the conveyor belt, and the white, yellow, blue and red small blocks represent goods in different regions. figure 2(a) is the layout of the 3D facility before the improvement, which is the record when the running time is 30 seconds, and the figure 2(b) is the 2D layout before the improvement, which is the record when the running time is 60 seconds. figure 2(c) is the improved 3D facility layout, which is also the record at 30 seconds of runtime. figure 2(d) is the improved 2D layout, which is also the record at 60 seconds.

Calculate the final result through MATLAB and use AutoCAD to draw a plan topology diagram of the facility layout before and after improvement, which is to prepare for the simulation experiment.

4.3. Simulation

Flexsim is a software for logistics system simulation. It can help the users establish and plan the simulation model of process design. The facility planning scheme obtained using the SLP method cannot be implemented on site. Only simulate the actual situation with Flexsim software.

All the data are from the actual site records, and the record time is 30 days; the distribution of sorting and receipt obedience is the simulation of the actual situation. And under the same conditions and at the same time, the quantity of the goods sorted before and after the improvement was compared, and the purpose of verifying the improvement plan and model was finally achieved.

Table 1. Experiments data of simulation

| Subject       | Time(3600s) Before | Time(3600s) After |
|---------------|--------------------|------------------|
| Total Sorting | 2323               | 10582            | 20646 | 109985 |
| After/Before  | 4.55               | 5.33             |

*Where ‘Before’ is before the improvement, ‘After’ is after the improvement.*
Under the condition that other parameters are the same, the only change is the layout of facility units. Run simulation models before and after improvement, 3600s and 36000s respectively. Record the experiments outcome and compare it, as is shown in table 1.

From table 1. We can know that when the simulation time is 3600s, the total amount of sorting after improvement is 4.55 times before improvement and it was improved to 5.33 when the simulation time is 36000s.

5. Conclusion
This paper focuses on the modelling and simulation based on the improved SLP facility planning method. By combining the multi-objective decision model with the traditional SLP method, the defects of the traditional SLP method are largely compensated. Based on the existing facility layout, the layout was re-arranged using the improved optimization model, and the facility layout before and after the improvement was simulated using Flexsim software. Experimental results show that the improved facility layout has an overwhelming advantage over the previous facility layout, which also verifies the effectiveness and availability of the algorithm and model.

However, there are still some deficiencies in this paper. For instance, the improved SLP method still has a small number of artificial scoring links. Although it is small, it will still affect the final layout plan. This unquantifiable problem will cause deviations in the layout of the facilities. Although this deviation will be small.

Subsequent research will continue to focus on how best to quantify the relationship between facilities, while focusing more on the establishment of the model.

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