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Research on the Optimization of the Facility Layout of Efficient Cafeterias for Troops

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***Abstract*—**Background: A facility layout problem (FLP) is an NP-complete (non-deterministic polynomial) problem, for which is hard to obtain an exact optimal solution. FLP has been widely studied in various limited spaces and workflows. For example, cafeterias with many types of equipment for troops cause chaotic processes when dining. Objective: This article tried to optimize the layout of a troops' cafeteria and to improve the overall efficiency of the dining process. Methods: First, the original cafeteria layout design scheme was analyzed from an ergonomic perspective and two new design schemes were generated. Next, three facility layout models were designed, and further simulation was applied to compare the total time and density of troops between each scheme. Last, an experiment of the dining process with video observation and analysis verified the simulation results. Results: In a simulation, the dining time under the second new layout is shortened by 2.25% and 1.89% ($p<0.0001$, $p=0.0001$) compared with the other two layouts, while troops-flow density and interference both greatly reduced in the two new layouts. In the experiment, process completing time and the number of interferences reduced as well, which verified corresponding simulation results. Conclusion: Our two new layout schemes are tested to be optimal by a series of simulation and space experiments. In future research, similar approaches could be applied when taking layout-design algorithm calculation into consideration.

***Keywords*—**Troops' cafeteria, layout optimization, dining efficiency, AnyLogic simulation, field experiment.

I. Introduction

THE problem of spatial layout is to reasonably place some objects in a space in accordance with certain requirements, or to divide a space into a combination of many small spaces to place sets of objects in effective ways, to allow greater efficiency in utilization of limited resources. However, layout problems are known to be complex and NP-hard (non-deterministic polynomial), which leaves a lot of room for growth and development of layout design strategies. Generally, necessary steps to raise and refine a new layout design involve: (1) formulating the layout design problem, (2) analyzing the design problem, (3) searching for alternative layout designs, (4) evaluating the layout design alternatives, (5) selecting the preferred design, (6) specifying the layout design to be installed [1]-[3].

There are many researches on optimization and evaluation of facility layout in different scenarios with various approaches. Systematic Layout Planning (SLP) is oriented to solve layout problems by collecting input data and analyzing the actual relationship activity and material flow [4]. SLP has been widely applied on the layout design of railway workshop [5], food processing [6] and production industry [7]. What is more, other researchers have facilitated a comprehensive method for Sustainable Facility Layout Problem (SFLP) [8], [9], intending to minimize the operating cost. Besides, ergonomics is usually considered to support designers to identify the relationship between the layout and human abilities and decrease loads' effect on tasks completion. These principles have been widely adopted on the study of catering operation process on the electric multiple units [10], high-speed rail express operation [5] as well as layout of cabs [11]. In the medical field, the facility layout problems of operating room, rehabilitation centers and other specific limited spaces have also been widely studied [12]-[15]. With the rapid development of technology, requirements on new layouts not only for high-intensity systems but for daily application supporting individual's work outputs are on the great prosperity. As invalid schemes would no longer adapt to limited space to fulfill the requirements of high efficiency, it would be demanding to apply the research of layout design and evaluation on infrastructure construction, such as troops' cafeteria for daily meals.

The scale of cafeteria for troops is relatively narrow, with many types of equipment involved in and chaotic processes for group dining. Without layout design based on ergonomics, short-term crowding may occur in the dining process, which elongates dining time and even causes trampling in emergency situations [16]. Therefore, it is necessary to put forward troops' cafeteria design requirements based on ergonomics. However, traditional layout only considers the placement of objects, ignoring workflow and multi-person collaboration in practical processes, lacking scientific and quantitative problem descriptions and solutions, considering only a single factor [17], [18].

Here, we mainly focus on regional characteristics and specific needs of military officers and soldiers' cafeterias. Based on the current facility layout, we proposed extra new layout plans utilizing ergonomic analysis. And we compared the original and new layouts by simulation and experimental methods. The best facility layout was further identified by analyzing the meal time, crowd density and the number of interferences.

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II. Methods

A. Analysis on the Existing Cafeteria Layout

Fig. 1 (A) shows the existing cafeteria layout. Due to the narrow space, more interferences will cause congestion if the layout cannot be designed reasonably. Since the tables for meal-getting under the existing layout are arranged in the innermost part of the room, the troops need to spend more time returning there and then leave after completing the meal. Under same capacity and size of equipment, the width of the aisle should be increased as much as possible. The aisle can be divided into the main aisle, which must be passed by most people and the optional aisle, which could be selected. These two types of aisles should be separated so that troops queuing and searching for seats will not interfere.

The tables are evenly distributed in four columns, with three in each column, which can accommodate 40 people. Considering the limited space, capacity requirements and the width of the aisle, dining tables on both sides are close to the wall. This kind of layout will obviously cause inconvenience for the inside diners and interferences among those outside. Therefore, the locations of dining tables should ensure the two ends of table rows connect with walls as less as possible, so that people can get in and out of the seat before and after the meal.

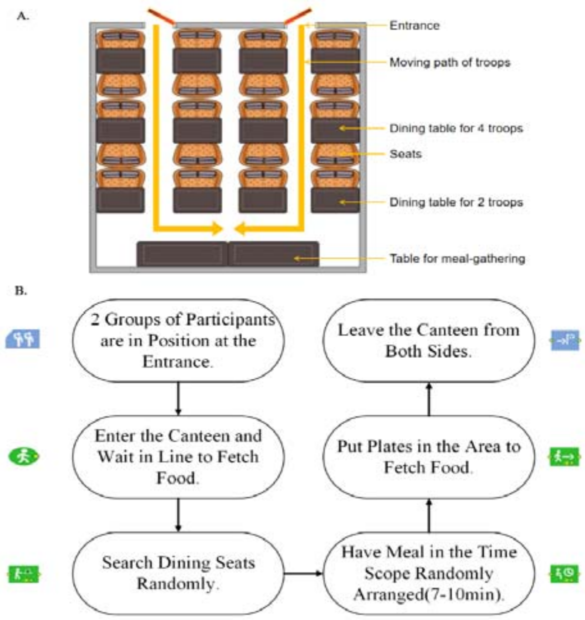

Fig. 1 The layout design schemes for troops' cafeteria (A) The original existing layout scheme. The size of the whole cafeteria and dining tables (combined with deck seats) are 5850 mm*5850 mm and 1000 mm*580 mm, respectively. The width of entrances is 500 mm (B) The standard process for dining in troops' cafeteria

B. New Cafeteria Layout Designs

Based on the above design requirements, we proposed two new layouts. First, the tables are arranged around the entrance of the cafeteria, so that troops can only leave where plates are returned, ensuring the shortest process for the person to complete the process. The first one is shown in Figs. 2 (A) and (B). In this new layout, the dining tables are placed at the entrance to place as many seats in the aisle as possible. The total number of aisle seats increase by 25%, with only six seats not in the aisle. The second one is shown in Figs. 2 (C) and (D). In the second new layout, the tables for meal-getting are also located at the entrance, but positions of tables and chairs are changed to reduce the number of seats against the wall to eight. Besides, the directions of the tables and chairs in the middle are changed to facilitate the troops on both sides shuttling between the two aisles.

Specific facility layout information included in the analysis for each scheme is shown in Table I.

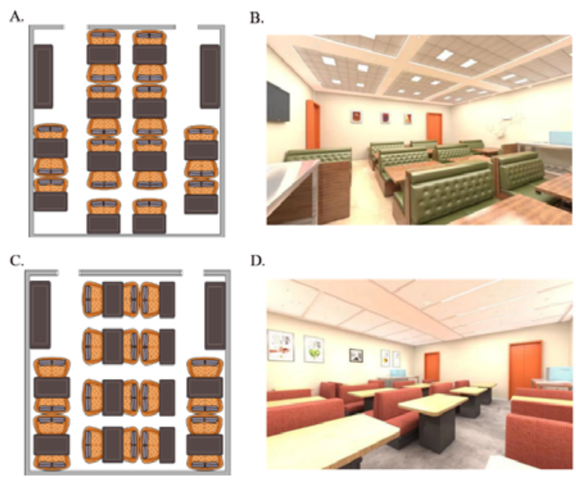

Fig. 2 The top view and overall fields of cafeteria space. A&B. The first new layout plan which was supposed based on ergonomic analysis. C&D. The second new layout plan which was supposed based on ergonomic analysis

TABLE I
Specific Facility Layout Information Included in the Analysis for Each Scheme

	Original layout	New layout 1	New layout 2
Capacity (person)	40	40	40
Seats near the door	10	6	8
Number of aisles	3	3	5
Tables for meal-gathering	Away from entrances	Near entrances	Near entrances

C. Model Construction And Simulation

AnyLogic (8.7 University Edition) was applied to build a pedestrian flow in the cafeteria with a large number of troop models. The density of troops in different areas exhibits the performance load of the service point and time spending in the specific dining process. Troop-cluster models were set to move in the continuous cafeteria space, reflecting the impact of different types of obstacles involving walls, tables and relative chairs. To compare the three cafeteria layouts proposed above, Monte Carlo simulation was used to analyze the time required to complete the entire dining process and movement interferences under different layouts [14]. As the simulation based on AnyLogic is different from the actual situation, it is necessary to conduct field experiments to verify the layout optimization.

D. *Experiment Verification*

Participants were recruited from Beihang University and were given written informed consents. The process was explained to all participants previously to avoid collecting inaccurate data. Since it is unrealistic to carry out the verification test process in a real troops' cafeteria, this study arranged the space and layout in advance for research and sorted out the troops' standard dining steps for experiments with collaborative processes. This arrangement considered the reliability of multi-person collaborative research involving a large base of people.

A certain process includes three parts: (1) start time and location, (2) duration, (3) end time and location. In paths allowing two people to pass, it is necessary to determine whether space-time interferences exist and whether collision occurs. In accordance with the simulation process, this experiment mainly focuses on the three layouts. In the original layout, the table for meal-getting is located close to the wall inside. Participants came in through two doors, queued up for meals, and then ate. After finishing the meal, they moved to the table for meal-getting to place their plates and finally left. In the other two new layouts, the participants completed the meal similarly. Fig. 3 shows how troops move in the whole experiment process.

Considering that the time for each participant to finish eating is different, it is necessary to allocate different time for the completion of the meal (Table II).

TABLE II
RANDOM MEAL TIME FOR EACH SPECIFIC FACILITY LAYOUT SCHEME

Participant number	Original layout (min)	New layout 1 (min)	New layout 2 (min)
1	7.2	9.3	9.2
2	8.3	9.8	8.5
3	8.7	7.4	9.3
4	9.4	7.0	8.3
5	7.6	8.2	9.3
6	9.4	8.6	8.9
7	9.4	8.5	8.8
8	9.9	7.1	8.0
9	7.5	9.4	9.8
10	8.7	8.0	9.6
11	8.0	8.1	8.4
12	8.5	8.5	8.2

In accordance with previous statistics, a troop usually needs 7 to 10 minutes to have a meal. Therefore, before the experiment, each participant was randomly assigned the meal duration after sitting down

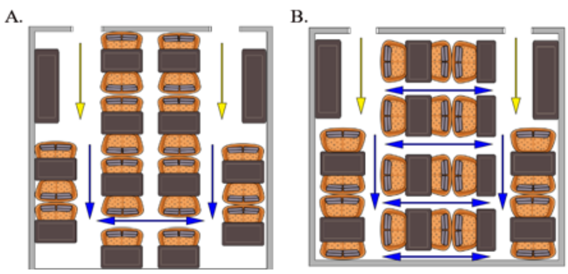

Fig. 3 Troops' moving direction in new layout 1 (A) and 2 (B) in the experiment process

To directly observe participant movements in the process, 42 cm*42 cm folding chairs were used to represent the dining area of each dining person. Tapes and color chalks were used to limit the boundaries of the cafeteria space, entrance and exit positions, dining area, and dining seating area. Two video cameras were used to record the process of the experiment. Timers were used to record the meal time for each individual and the whole participants. Cameras were used to record the whole dining process for further analysis. The video cameras were fixed in host and auxiliary positions located at the front and on the sides respectively. For all layout schemes, the time when the last participant completed the meal was recorded, which reflected the total time. Based on the principle of movement interferences in the multi-person collaborative process, two independent researchers observed the test video and analyzed the number of participants' movement interferences in each layout, ensuring the completeness and fairness of results.

E. *Statistical Analysis*

A general linear model using SPSS [19] was exercised to test the group differences of progress finishing time in AnyLogic simulations. All statistical analysis treated the group as an independent variable. The test from the global level was performed in comparison of whole dining process time under the original layout and the two optimization plans. The significance level was set as 0.05.

III. RESULTS

A. *The Process Finishing Time of Original and Proposed Layout Schemes*

Fig. 4 exhibits the results of the three facility layout schemes of troops' cafeteria after 100 times Monte Carlo simulation. In the three different layouts, time to complete the entire process of dining with maximum probability is 1180.2±34.7 s, 1175.8±32.4 s and 1153.6±45.9 s, respectively. The dining time under the second new layout is significantly shortened, with 2.25% and 1.89% efficiency improvement when compared with the existing design as well as the first new plan.

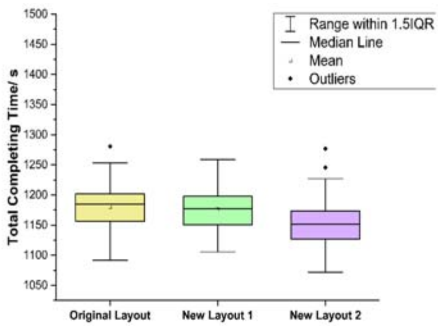

Fig. 4 The process finishing times of layout schemes under Monte Carlo simulation. Process finishing times were compared between the original design, the first and second new layout schemes. Significant difference was found under the second new plan when compared with the original scheme and the first new one (p<0.0001, p=0.0001). No significant difference was found under the first new plan compared with the original layout (p=0.364)

B. Space Interferences of Each Facility Layout Schemes

In the crowd density map, we found that the regional densities of troops are different between the existing design and the two new designs for optimization. Apart from the two entrance doors with similar results of troops-flow, difference of density is mainly located in the tables for meal-getting as well as the middle of table columns. Compared with the original design, both new designs show lower troops-flow. Under the original facility layout design, troops suffered more interferences near the entrance and the dining table during the entire dining process (Fig. 5 (A)), while people will only interfere more at the entrance and in the middle of cafeteria under the first new layout plan (Fig. 5 (B)). What is more, people will only interfere more at the entrance under the second new cafeteria layout scheme (Fig. 5 (C)).

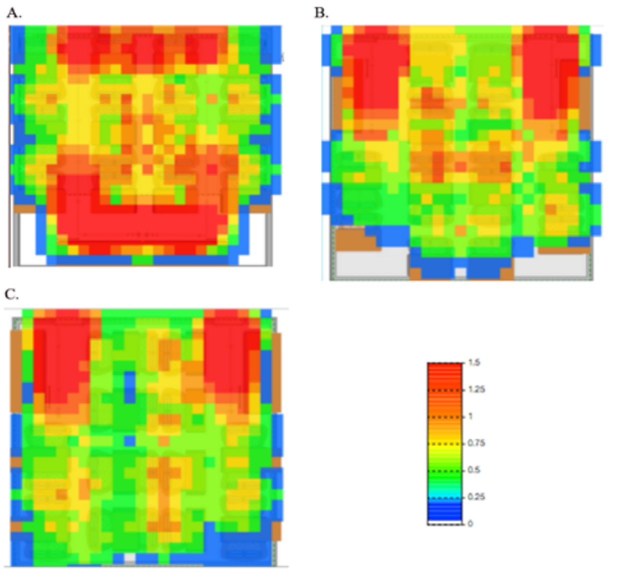

Fig. 5 Crowd density for each facility layout design. Each region in the cafeteria is covered by crowd density map which is accumulated during the whole process time. The values in the color-bar represent numbers of people in the unit area

C. Experiment Verification Results

As shown in Fig. (6A), the dining process costed 345 s under the original layout, and 12 interferences—10 seat-searching-related and two leaving-related—occurred during people movement process. Specifically, seat-searching-related interferences happened when people found their seats, while leaving-related ones happened when people collided with each other during the leaving process. Within our expectation, mutual interference times are consistent with the long time spent and the chaotic situation when the experiment was implemented. Also in Fig. 6 (A), the dining process costed 319 s under the first new layout, and the two kinds of interferences mentioned above occurred once respectively. Mutual interference times significantly reduced compared with the existing layout. Furthermore, it took 313 s to complete the dining process under the second new layout. Interference times further declined compared with the first new layout: seat-searching-related interferences happened only once and leaving-related interferences did not appear.

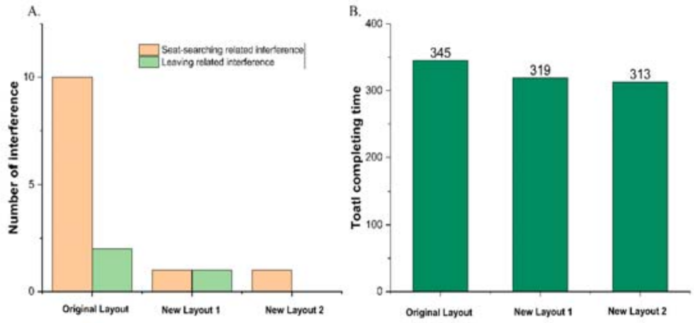

Fig. 6 The process completing times and the number of interferences for the verification experiments (A) The process completing times under the original layout and the two new layouts (B) The number of interferences was compared between all three layout schemes. The space interferences are divided into seat-searching-related ones and leaving-related ones

IV. Discussion

Based on the existing layout plan and considering the actual needs of troops, two new layout schemes were proposed and compared to the original one by Monte Carlo simulation and experiment verification. In the current study, we explored differences of dining process between three facility layouts. We found that the second improved scheme showed significantly reduced overall time and lower crowd density compared with the original and the first improved schemes during simulations. In addition, both optimized facility layout schemes showed reduced overall time and space interferences than the original one during experiments. Notably, total space interference times in experiments correspond to the crowd density in simulations. The experiments verified the overall results from simulations.

A. Between-Group Differences in the Different Layout Schemes

As the results of experiments, total process time declined by 7.5% and 9.3% under new layout 1 and layout 2 when global efficiency was considered. When focusing on interference times of two new layouts, it can be found that the less the number of transfers, the shorter the time required to complete, and the higher efficiency, which is consistent to the simulation results of the previous design. This section will discuss and analyze the results in the following aspects, including the seat searching process and positioning area, and the reasonableness of the aisle.

1. Seat-Searching Process

Participants started searching for dining locations after queuing for meal. This is when interferences are more concentrated, as it is the beginning of the troops' gathering and random dispersion. The three layout schemes have different characteristics in the process of seat-searching, which are also one of the decisive factors for the overall efficiency of the process.

(1) The distribution location of the table for meal-getting is one

of the biggest differences between the two new layouts and the existing layout. As described above, in two new layouts, the table for meal-getting is placed near the door, enabling troops to start getting meal as they enter the cafeteria, while in the existing layout, the table for meal-getting is located at the innermost part of the room. Therefore, all troops start looking for seats with no dispersion in the existing layout. However, the two new layout schemes ensure that troops start seat-searching in the middle of the room, so that they can be separated to both ends of the room, speeding up the dining-collecting process.

(2) Under the existing layout, the two teams' troops will meet after the meal, which increases the possibility of interferences, while the troops under the new layout will no longer meet in one place after being divided into two teams, which can reduce the amount of interferences and collisions.

(3) During the video analysis, it was noticed that the existing layout failed to separate the two teams of troops during the seat-searching process, which means the troops entering from the left door are more likely to shuttle to the right side. This phenomenon mainly results from the unreasonable location where troops meet after meal and the narrow aisle for seat-searching. As troops' seat-searching decisions were random and depended on personal subjective preferences, two new layout designs were optimized to prompt participants to scatter on both sides of the cafeteria space, thereby the dining process was accelerated.

2. The Position of Tray Storage

Since the table for meal-getting under the original layout was arranged in the innermost part of the room, only considering the convenience of conveying dishes to the kitchen, troops would return to the innermost part of the room first when completing meal and placing trays. However, the exit was far from where trays were stored, which increased the time for each participant to complete the process. In contrast, the table for meal-getting was arranged around the entrance in two new layouts. Therefore, troops could only leave after returning trays, ensuring the highest efficiency by reducing overall time.

3. The Design of Aisles

In common design principles, the number and width of aisles should be increased as much as possible to minimize interferences of two individuals during movement. As previously described, the main aisle and the optional branch aisle aim to reduce interference times in the queuing, meal-getting and seat-searching process.

In the original layout, the overall space only includes three longitudinal aisles, of which the left and right aisles are occupied when queuing, and the middle aisle would be used by the two teams of troops who have finished dining at the same time. It could be deduced from simulation and experiment results that the three aisles in the original layout were overloaded, and the interferences are amplified to the greatest extent. The dining tables are arranged horizontally in the second new layout, ensuring two main aisles as well as three horizontal aisles. In this way, the seat-searching and leaving process are independent, greatly reducing the likelihood of interferences. The main aisle ensures that troops are in line, and after the meal is completed, the two teams are separated, further reducing the number of interferences.

4. Proportion of Seats Against the Wall

The existing four-column dining tables are equally distributed, with three dining tables in each column, so up to ten people can be accommodated in each column. Due to the simplified design of the layout during this experiment, the mutual interferences between the table-mates was decreased. Therefore, considering the mutual influence between seats, the difference of efficiency under the existing space layout and the optimized ones will be further enlarged. However, it is worth noting that although the total time and the number of interferences of the second new layout are optimized compared with the first new layout, there are fewer seats beside the wall in the first new layout. Therefore, collaborative interferences at the same table will be lesser in the first new layout.

B. Subjective Feedback from Participants

After the experiment was finished, researchers also interviewed all participants for subjective experience of their process under three different designs. In accordance with the participants' feedback, the original layout is the worst, due to congestion concentrated in one place after getting meal and movement interferences when searching for seats. The two new layout designs can separate the individuals to both sides of the room, effectively improving the subjective experience of the subjects. The most positive feedback was collected under the second new layout, which was consistent with the results of total time and interferences in simulation. According to participants' responses, the second new layout reduced congestion of the main aisle while finding seats and enabled them to choose horizontal small aisles in the seat-searching process, therefore the experience was significantly improved compared with the original scheme.

C. Reliability of Layout Researches

Before the trial formally started, the researchers first conducted a field investigation of troops' dining time and concluded that the 40-person collaborative scene was infeasible to implement and would reduce the reliability of the results. In addition, video analysis will become difficult due to too much equipment. Therefore, in this experiment the number of participants was reduced to 12 to avoid uncertainty and chaos. In addition, we divided the dining area to restrict the participants' movement, thereby removed visual obstruction caused by the tables. Furthermore, 12 42 cm*42 cm folding chairs were used to replace real dining tables. Thus, it became more convenient for participants to search "dining seats".

Although the size of our simulated "cafeteria" was narrowed to 1/4 of the real scene in troops, space reduction rate in the experiment and the number of seats were still equivalent to the true environment, and interference detection was not affected. Before setting a time scope for each participant to finish the dining process, we investigated the troops' daily dining habits thoroughly in advance, and the 7-10 minutes range was tested based on such knowledge. Moreover, we generated a 12*3 matrix of random numbers between 7 and 10 in MATLAB and distributed each column of the matrix to 12 participants under each layout. Therefore, time-to-go methods were viable to represent the dining process in the cafeteria.

D. Limitations

Firstly, both two new layout schemes were designed in accordance with ergonomic principles, which are relatively subjective and lack of quantification. For future research, facility layout algorithms such as genetic algorithm and ant colony optimization could be utilized for further improvement of cafeteria for troops. Secondly, field models of simulations which were constructed based on 40-troop dining process and space are not consistent with the simplified environment for experiments. Therefore, the absolute results of simulations and experiments are not compatible, but only qualitative analysis for the trend is reasonable. For future research, more specific experiment scenes could be constructed for more reliable verification.

V. Conclusions

In this study, a set of Monte Carlo simulations and field experiments was conducted under three different cafeteria layouts for troops, with the aim of verifying effectiveness of the layout optimization. Data analysis on process completing time, crowd density, subjective feedback and interferences times revealed improved efficiency of the two new layouts and superiority of the second new layout. In the future research, more robust algorithms can be used to propose new layout designs, then combination of simulation and experiments is expected to verify the layout improvement.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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