Optimizing production layout and capacity via FlexSim—A case study of Y factory

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Abstract. Production capacity maximization and cycle time reduction are considered two of the most important issues for general factories. The paper applies Systematic Layout Planning (SLP), process balance, and system simulation to a small condense units manufacturer to enhance its production capacity and reduce cycle time. The developed solution shortens the total traveling distance by 81.25% and reduces the original travel time by 61.76%. In addition, we calculate the number of machines needed by process balancing and decrease the original cycle time by 64%. It is found that the proposed approach improved both cycle time and travel distance, and free up considerable capacity for manufacturing of other condensing units product types.

Keywords: FlexSim; system simulation; Systematic Layout Planning; cycle time reduction; process balance

1. Introduction
Globalization has put considerable pressure on small manufacturers to optimize production processes, e.g., by redesigning production facility layouts to reduce transfer time and effort, and by eliminating bottlenecks in production lines [1]. This research aims to reduce the cycle time in a small manufacturer of condensing units (Y factory). The factory produces different types of products including customized products. Each order is at a 50-unit scale. Observation of Y factory’s production line discovered efficiency flaws and bottlenecks, such as non-value travel from operators carrying heavy Work In Process (WIP).

We applied SLP to rearrange optimize factory floor efficiency, identified production bottlenecks, calculated the potential production capacity, and adjusted the number of machines at every station through process balancing. Finally, we used FlexSim, a powerful system simulation tool, to verify our modification and performance. [2]

The constraints of the present study include the following: (1) Station areas do not overlap; (2) Only equipment and product flow are considered; (3) The process ends when the product is finished, without consideration of shipping; and (4) The lead product by output volume is adopted as the test product. Other product types are not considered.

2. Methods
The project uses SLP, process balancing, and system simulations. An operation flow chart was developed to identify the manufacturing process. The principles used to draw the operational flow chart are listed in Table 1. SLP is a theory used to arrange production facilities by locating areas with high
frequency and logical relationships close to each other, thus optimizing speed and efficiency in material flows by minimizing transport, cost, and travel time, while maximizing safety. SLP requires an activity relationship chart, activity relationship diagram, space relationship diagram, and block layout diagram to arrange the layout step by step. [3-5] An activity relationship chart is a tabular means of displaying the closeness rating among all pairs of activities or departments. An activity relationship chart includes six closeness ratings which may be assigned to each pair of departments, as well as nine reasons for those ratings (each denoted by a reason code). Examples are shown in Figures 1 and 2. The space relationship diagram shown in Figure 3 shows the activity relationship after considering the actual space of every workstation. The block layout diagram, as shown in Figure 4, is used to adjust the spatial relationship diagram to fit the actual space of the workshop.

Process balancing is a technique used to minimize the Effective Station Cycle Time, which is the average cycle time needed for a station to finish processing a product, and is used to identify production bottlenecks. Figure 5 shows the steps for process balancing.

**Table 1.** Legends for operation process chart.

| No. | Chart | Illustration |
|-----|-------|--------------|
| 1   |       | Horizontal line represents the entrance of the material. |
|     |       | Vertical line means the steps of manufacturing |
| 2   |       | Typical process flow chart |
| 3   |       | A re-entrant process flow |

**Figure 1.** Activity relationship chart
Figure 2. Activity relationship diagram.

Figure 3. Space Relationship diagram.

Figure 4. Block layout diagram.

Figure 5. Steps to Process Balance.

Terminology related to process balance is listed below. Figure 6 integrates the formula for process balancing.

- **Takt Time**: Takt time is the average time between the start of production of one unit and the start of production of the next unit, when these production starts are set to match the rate of customer demand.
- **Actual Process Cycle Time (APCT)**: The actual time needed for a process or machine to finish processing a product.
- **Actual Station Cycle Time (ASCT)**: The actual time needed for a workstation to finish processing a product.
- **Effective Process Cycle Time (EPCT)**: The average time needed for a process or machine to finish processing a product.
- **Effective Station Cycle Time (ESCT)**: The average time needed for a workstation to finish processing a product.
- **Number of machine needed**: The number of machines needed to ensure bottleneck-free production.
- **Line Balance Rate (LBR)**: It is a performance index utilized in process balancing and to evaluate the average utilization rate of each workstation, where a higher LBR indicates a smaller deviation of the effective cycle time between workstations and reduced production workstations, thus greater efficiency.
• Line Balance Efficiency (LBE): LBE is a performance index for process balancing. It evaluates the average utilization rate of each workstation. A higher LBE indicates a smaller deviation of the effective cycle time between each workstation and reduced production bottlenecks, thus greater efficiency.

A powerful system simulation software, FlexSim, plays an important role as a verification tool in this research. We built two models via FlexSim. The first model represents current status of Y factory. The other model represents the situation after applying the modifications. Thus, we have the opportunity to examine the performance of our approaches [6, 7]. Figure 7 revealed an exemplar of FlexSim model.

![Figure 7. FlexSim model.](image)

3. Results and Discussion

3.1 SLP and simulation

The Bill of Material (BOM) of Y factory was used to identify the relationship between material and final product. A condensing unit is composed of brass tubing, aluminium flake, and an iron shell. An operation process chart was constructed to provide a systematic understanding of product processing. Shown in Figure 8, the product needs to go through seven processes in a particular order. The travel distance of the operator was measured and set as a Key Performance Indicator (KPI) for optimization.

Figure 9 shows the activity relationship diagram based on the processing activity sequence in the storage and production areas, measuring the close relationship between the two areas. Workstations with priority in the product processing sequence should be in close proximity, and the degree of closeness between the two workstations is converted into relationships of descending closeness denoted by A, E, I, O and U, where U denotes nearly no communication between two workstations. Figure 10 shows a spatial relationship diagram based on the activity relationship diagram. We use the spatial relationship diagram to develop the block relationship diagram (Figure 11). Finally, we adjust the spatial relationship diagram to fit the actual area of Y factory and come up with an improved layout. Figures 12 and 13 show the floor plan before and after modification, respectively. Table 2 shows station names by code.

After completing SLP, we construct the layout, and design the flow by coding into our FlexSim model to emulate the travel distance and time. The revised layout shortens the distance between the brass bending workstation and pipe insertion workstation from 7 meters to 1 meter. Reduced travel distance between workstations also improves material handling efficiency. The tables below show that the overall cycle time and travel distance are significantly reduced during the process (Total benefit increased 81.25% by distance reduced and 61.76% by travel time reduced). Figures 14 and 15 respectively show the FlexSim model before and after modification, while Tables 3 and 4 respectively summarize travel distance and travel time after SLP.

3.2 Process balance and simulation

The improved workstation layout shortens the distance between the workstations and transportation time, but we still seek a greater reduction in cycle time using the process balancing method to adjust the production capacity. The data needed for process balancing is displayed in Table 5.
Figure 8. Operation process chart of Y factory.

Figure 9. Activity relationship chart of Y factory.

Figure 10. Spatial relationship diagram of Y factory.

Figure 11. Block relationship diagram of Y factory.

Figure 12. Floor plan before SLP.

Figure 13. Floor plan before SLP.
Table 2. Codes of each station.

| Code | Station name     | Code | Station name     |
|------|------------------|------|------------------|
| (1)  | Gate             | (7)  | Welding          |
| (2)  | Material storage | (8)  | Leak detect      |
| (3)  | Flake punching   | (9)  | Assembly         |
| (4)  | Elbowing         | (10) | Cutting          |
| (5)  | Pipe piercing    | (11) | Bending          |
| (6)  | Pipe expansion   | (12) | Final product storage |

Table 3. Comparisons of distances after applying SLP.

| Distance | Before (m) | After (m) | Benefit (%) |
|----------|------------|-----------|-------------|
| (2) – (3)| 2          | 1         | 50.00%      |
| (4) – (5)| 7          | 1         | 85.71%      |
| (5) – (6)| 2          | 1         | 50.00%      |
| (8) – (9)| 12         | 1         | 91.67%      |
| (9) – (12)| 9     | 2         | 77.78%      |
| Total benefit | 32     | 6         | 81.25%      |

Table 4. Comparisons of travel times after applying SLP.

| Travel time | Before (s) | After (s) | Benefit (%) |
|-------------|------------|-----------|-------------|
| (2) – (3)   | 5          | 2.5       | 50.00%      |
| (4) – (5)   | 25         | 14        | 44.00%      |
| (5) – (6)   | 10         | 8         | 20.00%      |
| (8) – (9)   | 41         | 8         | 80.49%      |
| (9) – (12)  | 38         | 13        | 65.79%      |
| Total benefit | 119     | 45.5      | 61.76%      |

Table 5. The data needed for process balancing.

| Machine name       | APCT | EPCT | Batch size | Takt time | No. of machine needed |
|--------------------|------|------|------------|-----------|-----------------------|
| Elbowing machine   | 506  | 506  | 1          | 288       | 1.8                   |
| Flake punching machine | 82   | 82   | 1          | 288       | 0.3                   |
| Pipe piercing machine | 30   | 30   | 1          | 288       | 0.1                   |
| Pipe expansion machine | 42   | 42   | 1          | 288       | 0.1                   |
| Welding machine    | 234  | 33   | 7          | 288       | 0.8                   |
| Leak detector      | 95   | 95   | 1          | 288       | 0.3                   |
| Assembly machine   | 120  | 120  | 1          | 288       | 0.4                   |

Process balancing reveals the need for an additional brass-bending machine, while the number of other machines remains static. Furthermore, we apply the revised workstation layout in Section B, and then simulate this scenario through FlexSim. We find that the cycle time for finishing the first product of an order is significantly reduced by 46.06% from 4220 s to 2640 s. The cycle time for producing a batch of 50 (i.e., the minimum order size) is shortened by 64.40% from 29,054 s to 14,900 s. Table 6 briefly shows the cycle time improvement after applying process balancing. Among the important indicators of process balance, LBR increased from 15.69% to 28.43%, and LBE increased from 23.17% to 37.01%. Despite these improvements, the LBR and LBE absolute values are still below 50%. This indicates that the Takt Time of the product can be shorter, meaning that there is still plenty of room to increase order sizes to make better use of capacity. Table 7 compares LBR, LBE, and the balance rate after applying process balancing. Figure 16 shows the FlexSim model after process balancing and SLP.
Figure 14. FlexSim model (before SLP).

Figure 15. FlexSim model (after SLP).

Table 6. Cycle time improvements for products.

| Cycle time (s) | Before | After | Benefit                  |
|---------------|--------|-------|--------------------------|
| One product   | 4220   | 2640  | Decrease by 46.06%       |
| 50 products   | 29054.48 | 14900 | Decrease by 64.40%       |
| Average       | 581.0896 | 298   | Decrease by 64.41%       |

Table 7. Comparisons of performance after process balancing.

| KPI          | Before | After | Benefit                  |
|--------------|--------|-------|--------------------------|
| LBR          | 15.69% | 28.43%| Increase by 12.75%       |
| LBE          | 23.17% | 37.01%| Increase by 13.84%       |
| Balance Delay| 76.83% | 62.99%| Decrease by 13.84%       |

Figure 16. FlexSim model after process balancing.
4. Conclusions
Production capacity maximization and cycle time reduction are considered two of the most important issues for general factories. This study uses SLP, process balancing, and FlexSim simulation to develop a solution which improved both cycle time and travel distance. The developed solution shortens the total traveling distance by 81.25% and reduces the original travel time by 61.76%. Additionally, the number of machines needed by process balancing and decreases the original cycle time by 64%, freeing up considerable capacity for manufacturing of other condensing unit product types. The approaches applied in Y factory are suitable for other small manufacturers as well.

The layout of Y factory needs to be rearranged to maximum production capacity. Adding one brass-bending machine will simultaneously reduce the travel distance and cycle time. It should be noted that there are limitations of this study including: (1) Ignoring cost analysis for more comprehensive insights and adjustments; (2) The scope of research to facilities doesn’t consider multiple production floors.

5. References
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