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Research on Balance Optimization of Garment Production Line Based on Industrial Engineering Methods

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Abstract: In the context of the garment manufacturing industry, there has been a continuous improvement in the requirements for production efficiency and resource utilization. Consequently, the optimization of production line balancing has become a key issue for enterprises to enhance their competitiveness. This paper investigates the shirt production line of a sewing workshop of a garment enterprise. It addresses the problems of uneven distribution of work processes, prominent bottleneck stations, and long production cycles. The paper applies the theory and method of traditional industrial engineering to optimize the workforce, production process, equipment management, and so on. Initially, standard working hours are determined through job measurement and time study; Industrial engineering methods are then used to optimize and balance the processes of the production line; and the production line balance rate and smoothness index are introduced to evaluate the improvement effect. The experimental results demonstrate that the optimized production line balance rate increases from 39.5% to 62.8%, and the production imbalance loss rate decreases from 60.5% to 37.2%. The method proposed in this study provides theoretical support and practical tools for the apparel manufacturing industry, and it has a significant reference value for realizing lean production.

Keywords: Apparel production line; Line balancing; Bottleneck process; Beats

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1. Introduction

In recent years, the global apparel market has seen a surge in competition, with consumers demanding greater variety and customization. This has created significant challenges for apparel manufacturing companies, who must respond by reducing production cycles, lowering operating costs, and enhancing flexibility. Given its status as a labor-intensive industry, the efficiency of apparel production is directly affected by the level of production line balancing. The objective of line balancing is to achieve a balanced and efficient production process through the rational allocation of work processes and the optimization of work station configuration. This is achieved by reducing idle time, lowering work-in-process inventory, and increasing overall production capacity [1]. However, the production of apparel is characterized by complex processes, strong interdependencies between processes, and an increased demand for multi-species small-lot production. To date, scholars both domestically and internationally have conducted extensive research on the production line balancing problem, primarily concentrating on the modeling and resolution of the classical assembly line balancing problem, and progressively extending to the consideration of dynamic adjustment, multi-objective optimization, and other complex scenarios. In the domain of apparel manufacturing, the majority of research endeavors concentrate on the areas of process splitting, man-hour measurement, and workstation layout optimization [2]. This encompasses the application of action analysis by the MTM method or the integration of heuristic algorithms to enhance workstation allocation [3]. However, the extant research is inadequate in two respects. Firstly, the unique flexibility requirements of apparel production have not been fully incorporated into the model. Secondly, the traditional static balancing strategy is difficult to adapt to the dynamic perturbations, such as human fluctuations and equipment failures, in the production process. This results in the theoretical optimization deviating from the actual effect.

In this paper, the focus is on a shirt production line of an enterprise, which is selected as the research object. Through job determination, the bottleneck of the production line is identified, and industrial engineering techniques and methods are applied to analyze each process on the production line. The principles of ECRS (Elimination, Consolidation, Rescheduling, and Simplification) and the principle of economy of action are applied to reduce stagnation and waiting due to the difference in time, and ultimately to improve production efficiency. Concurrently, the efficacy of these enhancements is appraised through the utilization of indicators such as the production line balance rate, a paradigm shift from the conventional one-person, one-station fixed-person system. This paradigm shift facilitates enhanced productivity in response to fluctuations in demand without necessitating an increase in personnel. The study proffers solutions for the enhancement of production lines within analogous enterprises.

2. Industrial engineering-related methods

2.1. Methodological research

The methodology under scrutiny here is founded on the premise of meticulously documenting and analyzing prevailing production and processing methodologies with the objective of identifying and establishing more efficient and rational workflows. Adopting this methodology enables companies to optimize production processes and procedures, reduce superfluous handling waste, foster optimal human-machine collaboration, and institute standardized work practices, thereby achieving substantial enhancement in work efficiency. The methodology employs a systematic approach to analyze the production system comprehensively, with the objective of resolving various issues in production optimization. This systematic approach encompasses a wide range of levels, from macro to micro. Specifically, the methodology encompasses three key domains: process analysis, job analysis, and motion analysis. Through these detailed analyses, companies can identify bottlenecks and redundancies in the production process, providing a solid foundation for the development of improvement strategies [4].

The 5W1H analysis method is a systematic approach to problem exploration (**Table 1**). Its objective is to reveal the nature of a problem and find a solution by asking questions and analyzing the problem several times in a row from the six key dimensions: purpose, cause, time, place, people, and method [5]. This method focuses on asking in-depth questions about the work or problem under study. Through an exhaustive question-and-answer process, it pinpoints the problem and develops improvement measures accordingly. In instances where the initial analysis and proposed measures prove ineffective in achieving optimal outcomes, alternative methods or strategies may be considered for further problem resolution. The following section details specific questioning methods employed in this analysis.

Table 1. 5W1H questioning method

Perspective	1st question	2nd question	3rd question
Goal	(What)	Necessity	Is there a more suitable match?
Rationale	(Why)	Why do you have to do it?	Is it not necessary to do
Timing	(When)	Why do it now?	Is there a more appropriate time elephant
Point	(Where)	Why do it here?	Is there a more suitable location
Officers	(Who)	Why this man?	Is there a more suitable candidate
Methodologies	(How)	Why it's necessary	Availability of more appropriate methods and tools

The "ECRS" principles are utilized in conjunction with the "5W1H" analysis to enhance the efficiency of the production process. The "ECRS" principles, which stand for "Eliminate, Combine, Rearrange and Simplify", are employed following the collection of comprehensive descriptions from the staff regarding the present status of the production line. The implementation of these principles, guided by the staff's detailed descriptions, enables the optimization of relevant processes, thereby enhancing production efficiency and reducing costs [6].

2.2. Operational measurement

Job measurement can be defined as the utilization of tools or methodologies for the estimation of the time required by skilled workers to execute a task in accordance with established job requirements. Prior to the implementation of this approach, a significant amount of idle time was observed, resulting in diminished productivity on the production line. This was attributable to the absence of a standard operating time for operators. The implementation of a standard operating time for a process provides operators with a reference point to motivate themselves to save time, effectively utilize the operating time, eliminate unnecessary time wastage, and enhance the output efficiency of the production line [7]. Among the numerous operation measurement methods, the stopwatch timing method is widely utilized for its high efficiency and good applicability. This method involves the utilization of a stopwatch timer and ancillary tools to directly and continuously time qualified operators according to the specified time, record the relevant parameters and working time, and set the relaxation rate according to the production situation, thereby arriving at the standard working time of the process. It should be noted that standard time includes normal time and relaxation time, i.e. standard time is equal to normal time plus relaxation time.

3. Theories related to production line equilibrium

3.1. Concept of line balancing

Production line balancing is predicated on the fundamental principles of industrial engineering, entailing the observation and analysis of the load degree of all processes on the entire production line. Through the process of adjustment and optimization of the workload of each process, the objective is to minimize the discrepancy between the work time of each process. The purpose of line balancing is to eradicate superfluous waiting time and enhance labor productivity. In the context of production line balancing, the establishment of constraints aimed at balancing the load of each process is paramount. This ensures that the total operating time of each process does not exceed its maximum capacity, thereby resolving the bottleneck time of the process experiencing congestion [8]. Moreover, the regulation of workload is intricately linked to the issue of process sequencing. An optimal work order can significantly enhance the efficiency of the production line, thereby reducing costs. Consequently, the optimization of work processes and the mitigation of bottleneck periods can reduce the waiting time of all processes, thereby reducing working hours and conserving human resources, while concurrently lowering costs, enhancing productivity, and ultimately, improving the efficiency of the enterprise's products.

3.2. Production line balance optimization steps

The following steps are recommended when optimizing production line balance.

The content of the work process must be determined. Research must be conducted on the enterprise production line to understand the process flow and the work content of each station.

Working hours must be measured and recorded. The stopwatch method must be used to measure the time used in each process, and abnormal data must be excluded. The evaluation coefficient and relaxation time must then be determined, combined with the on-site data, and the standard time must be calculated through the formula.

The collected data are then processed to identify the bottleneck station. The data are counted, and the bottleneck workstation is found more intuitively in the form of charts.

The evaluation index is then determined. The effect of production line optimization before and after the quantitative analysis needs to be carried out, according to the formula to calculate the production line balance rate, balance loss rate, smoothness index, and so on.

Analyze the identified problems and determine the underlying causes by engaging in communication with the workers, utilizing quantitative data and other relevant methods to identify defects in the production line and investigate the root causes of the issues.

Develop an improvement program. After conducting a thorough analysis of the aforementioned problems, formulate an improvement plan that is tailored to the specific circumstances of the production line.

3.3. Production line balance evaluation indicators

The evaluation of production line balance is primarily informed by the following categories of indexes.

3.3.1. Production line balance rate

The production line balance rate is an index used to assess the degree of balance and efficiency of the production line [9]. This is typically expressed as a percentage, with a higher rate indicating a more balanced process and a faster and more efficient operation of the entire production line. Conversely, a low rate of production line balance indicates potential bottlenecks within the production line, prolonged process times, or suboptimal production line design, necessitating adjustments and optimizations to enhance the balance rate. The formula for calculating the production line balance rate is as follows:

$$P = \frac{W}{n \times C} \times 100\% \qquad (1)$$

In this model, P denotes the production line balance rate, W signifies the total time of all processes, n represents the number of workstations, and C denotes the beat time of the production line.

3.3.2. Balance loss ratio

The Line Balance Loss Ratio is defined as the proportion of time expended on a production line due to the presence of non-essential waiting time and unnecessary movements. It is a metric used to assess the efficiency of the production line and the amount of time wasted, typically expressed as a percentage. A higher Line Balance Loss Rate is indicative of a longer duration spent on the production line, and a less efficient overall production process. Conversely, a lower line balance loss ratio signifies a more efficient operation on the production line. The formula for calculating the line balance loss ratio is as follows:

$$d = \frac{n \times C - W}{n \times C} \times 100\% = 1 - P \quad (2)$$

The evaluation criteria for the production line balance loss rate are delineated in **Table 2**.

Table 2. Evaluation scale for balance loss ratio

Equilibrium loss rate d	**d≤10%**	**10%≤d≤20%**	**d≥20%**
Hierarchy	excellent	virtuous	bad

3.3.3. Smoothness index

The production line smoothness index is a metric employed to evaluate the degree of smoothness of a production line. It quantifies the degree of variation and fluctuation between workstations on a production line over a specified time period, with a lower index indicating reduced variation and fluctuation in the production process, thereby enhancing productivity [10]. Conversely, an elevated smoothing index signifies greater variation and fluctuation within the production line, potentially compromising production efficiency and quality. By undertaking systematic monitoring and optimization of the production line smoothness index, enterprises can enhance the efficacy and quality of production, thereby ensuring more effective management of production schedules and plans, and ultimately, enhancing market competitiveness. The calculation formula for the production line smoothness index is as follows:

$$SI = \sqrt{\frac{\sum_{i=1}^{n} (C - Ti)^2}{n}} \quad (3)$$

SI denotes the smoothing index of the production line, whilst C represents the production beat of the production line. In addition, n denotes the number of workstations and denotes the operating time of the ith process in the production line.

4. Apparel line overview

4.1. Analysis of the current situation of the shirt production line

This paper analyzes and improves the shirt production line as a research object. The company is a small and medium-sized apparel manufacturing enterprise, which consists of several apparel production lines. Shirt production is a highly standardized process in the clothing manufacturing category. Its core processes usually include: fabric cutting > parts sewing (collar, sleeves, front piece, back piece, etc.) > assembly sewing > ironing and shaping > quality inspection > packaging. In comparison with other apparel categories, the production of shirts demands a higher degree of process precision and a strong dependence between processes. For instance, the assembly of cuff grommets must be completed before the eyelet locking process. The conventional production line predominantly employs an assembly line mode of operation, with workstations arranged following the sequence of the process. However, the overall process remains susceptible to bottlenecks, attributable to the automation level of the equipment and the efficiency of manual operation.

4.2. Measurement of process operating time

In the course of optimizing the production process and enhancing the efficiency of a shirt production line, it is imperative to accurately measure the working time of each process. In this study, the stopwatch timing method was employed to evaluate the working time of each process on the shirt production line. To minimize the impact of random errors, temporary disturbances, and individual outliers on the measurement results, the triple standard deviation method was implemented for data screening. For the selected processes, the study performed several independent stopwatch measurements and used the example of process 1 doorstop sticky lining for detailed illustration. To ensure the accuracy of the data, the study performed 8 observed measurements for this process and recorded the results in **Table 1**. Initially, the results from the eight measurements were aggregated and then divided by the number of measurements to derive an average value, designated X. This average value is representative of the centralized trend of the results from multiple measurements and provides a more accurate reflection of the actual working hours. Following the determination of the mean value X, the deviation of each measurement from X was calculated. The sum of the squares of these deviations was then averaged, and the square root of this value was taken to obtain the standard deviation. The standard deviation is a measure of the dispersion of the measurement data, and according to the principle of triple standard deviation, measurements that are more than three times the standard deviation of X are considered outliers and should be eliminated. This step serves to minimize the impact of random errors and outliers on the final results. Subsequent to the elimination of outliers, the remaining measurements are aggregated and divided by the actual number of measurements (i.e., the number of measurements after removing the outliers) to obtain the screened average working hours. This average working time is more representative of actual working time and can provide a robust foundation for the optimization of the production line.

In summary, the employment of the stopwatch timing method, the triple standard deviation method, and multiple observation measurements have enabled the derivation of more accurate and reliable working hour data for the process. This, in turn, provides a strong guarantee for the optimization of the production line and the improvement of efficiency. The working hour measurement results of process 1 access control sticky lining are shown in **Table 3**.

Table 3. Process time measurement datasheet

Number of observations	1	2	3	4	5	6	7	8
Observation time (s)	11.1	10.3	9.8	10.1	9.7	9.6	10.2	10.8

Following the completion of the work-time measurement, the measured data must undergo scientific screening to ensure the subsequent execution of the work is conducted in an orderly manner, and to prevent inaccuracies in the measurement data arising from measurement errors and other factors. This paper employs the triple standard deviation method, which stipulates that the normal value range of a group of data should be within the interval of the arithmetic mean ±3σ of the group of data. In instances where the measured data deviates from this range, it necessitates the elimination of the data from further analysis. The specific calculation method is outlined as follows.

Assuming that the observation time for a particular operating unit is $X_1, X_2, X_3 \ldots\ldots X_n$, the average value of this set of data is:

$$\overline{X} = \frac{\sum_{i=1}^{n} Xi}{n} \quad (4)$$

The standard deviation is:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(Xi-\overline{X}\right)^2}{n-1}} \quad (5)$$

Set the upper limit of deviation to $\overline{X} + 3\sigma$, the lower limit of deviation is $\overline{X} + 3\sigma$, and the remaining values are considered outliers and should be eliminated. Following the elimination of these aberrant values, the mean time measurement results of each process are determined using the standardized formula: standard time = observation time x assessment factor x (1 + relaxation rate). The standard working hours for each process are presented in **Table 4**.

Table 4. Operational standard time

Process number	Job element content	Standard working hours/s
1	Access control adhesive lining	10.6
2	Folding iron access control	21.9
3	Receive the front piece of the province	24.8
4	Receive the back piece of the province	16.2
5	Labeling (Close)	5.6
6	Shoulder seams and side seams (Lock)	27.2
7	Shoulder seams and side seams (Inverted)	28.8
8	Ironing (Saving) seams, folding, and Ironing (Hemmed)	34.2
9	Collars sticky lining hooked	9.6
10	Collars clean sample	24.8
11	Trimming turning ironing	26.5
12	Collar corner shaping	16.1
13	Sole collar	54.9
14	Sleeves closed side seams	7.6
15	Locking side seams	10.5
16	Inverted ironing side seams, folding ironing cuffs	18.1
17	Cuffs plain line	24.2
18	Sole sleeves	66.3
19	Locking sleeve cages	27.5
20	Body hem plain line	20.9
21	Locking eyelets	46.2
22	Buttons	45.5
23	Ironing whole	34.6

4.3. Analysis of production line balance

The standard operating time calculated according to the above steps shows that the number of stations n = 23; the bottleneck time c = 66.3 seconds and W = 602.6 seconds, which gives the line balancing rate of the shirt production line:

$$P= \frac{602.6}{66.3\times 23} = 39.5\%$$

Shirt line equilibrium loss rate:

$$d = 1 – P = 1 - 39.5\% = 60.5\%$$

Shirt production line smoothness index:

$$SI = v42.83$$

The relevant data collected during the on-site research indicates that the balance rate of the shirt production line is 39.5%, while the balance loss rate is 60.5%. This suggests that the discrepancy in operating time between workstations has resulted in significant waiting and inventory waste. The calculation of the smoothing index of the production line yielded a result of 42.83, which is indicative of significant dispersion in the total time allocated to each workstation. This finding suggests that the time deviation between workstations is substantial, and the workload between different workstations is imbalanced. In conclusion, the overall balance of the shirt production line is suboptimal, with a considerable loss in operating time and scope for enhancement.

4.4. Analysis of production line problems

It is evident that process 18, which is identified as the key bottleneck process in the shirt production line, exhibits a production beat of 66.3 seconds, which is considerably longer than the production cycle of other processes. This has a substantial impact on the balance of the production line, leading to a considerable decline in overall efficiency. To meet the resource demands of this bottleneck process, the production line often needs to allocate additional resources, but this may lead to an imbalanced distribution of resources across different processes, with some processes being idle due to excess resources and others being limited due to a lack of resources. This results in inappropriate consumption of resources and unnecessary increase in production costs, and constitutes a significant negative impact on the overall resource utilization efficiency of the production line. This has been shown to result in excessive consumption of resources and unnecessary escalation in production costs, which in turn negatively impacts the overall resource utilization efficiency of production lines. Moreover, Process 18 is characterized by a high workload and high-intensity work pressure, which pose a significant challenge to the physical and mental health of employees and can easily lead to employee fatigue and overwork. Prolonged exposure to such a high-pressure working environment may have a detrimental effect on the accuracy and efficiency of employees' work, which in turn poses a potential threat to product quality. Consequently, the timely optimization and enhancement of Process 18 has become a pivotal concern, with the objective of enhancing the overall efficiency of the production line, ensuring product quality, and promoting the rational utilization of resources.

The division of workstations is not reasonable. The configuration of the shirt production line workstations gives rise to a significant non-equilibrium problem, which is reflected in the considerable differences in the operational elements covered by the workstations, as well as the substantial fluctuations in the required operating time. These factors directly lead to an imbalance of the task load between the workstations. When a workstation is overloaded with tasks, workers are compelled to complete substantial workloads within a constrained timeframe. This can lead to the exacerbation of physical and mental fatigue, as well as a decline in product quality due to the rush to achieve results. Moreover, it can result in the onset of health problems, which can further increase the unplanned downtime of the workstations and hinder the implementation of the established production plan. Conversely, if the quantity of tasks at a workstation is inadequate or the tasks are unduly elementary, workers may perceive the work as unchallenging, which can engender a sense of burnout. This, in turn, can diminish job satisfaction and engagement, as well as compromise the overall operational efficiency of the production line. This, in turn, can result in the underutilization of resources and the occurrence of superfluous losses. The implementation of a refined workstation division strategy is therefore proposed as a means to optimize the allocation of resources and reduce unnecessary resource wastage. This strategy encompasses but is not limited to, the reduction of material wastage, labor costs, and equipment idling and downtime. The process of workstation segmentation necessitates meticulous consideration of the characteristics inherent in each work element, the judicious estimation of work time, and the alignment of worker capacity with workload. This is undertaken to achieve a balanced distribution of workload among workstations, thereby enhancing the overall efficiency and economic benefits of the production line.

5. Optimization analysis of shirt production line

5.1. Optimization of bottleneck processes

The bottleneck process imposes a limitation on the capacity of the entire production line and frequently necessitates additional resource investment, such as supplementary equipment and manpower. A detailed examination of the bottleneck process in the shirt production line, designated Process 18, which requires 66.3 seconds, utilizing the 5W1H analysis and integrating the ECRS principles (Eliminate, Consolidate, Reorder, and Simplify), revealed that Process 18 could not be eliminated nor further simplified. Consequently, measures were implemented to optimize this bottleneck process by introducing specialized equipment and an operator. However, subsequent improvements to Process 18 led to Process 13 emerging as a new capacity bottleneck, exhibiting a comparable operational pattern to Process 18. Consequently, a decision was made to implement the same strategy employed for the enhancement of Process 18, namely the incorporation of a dedicated machine and an operator into Process 13, with the objective of reducing its operational duration.

5.2. Improvement of workstation division

The current configuration of the workstation arrangement for shirt production exhibits a state of evident chaos, characterized by a disproportionate distribution of workload across workstations. This imbalance exerts a detrimental influence on the equilibrium of the production line. To address this issue, this study employs the 5W1H analysis method and the ECRS principle, with the objective of re-planning and optimizing each process within the shirt production line. The 5W1H analysis method was employed to guide the investigation, with a series of key questions being posed for each process of the shirt production line. These included inquiries into the necessity of process consolidation, the specific implementation of the merger, the integration of the merged process into the overall production process, the operator responsible for the merged process, the timing of the combined process, and the specifics of the combined process. The subsequent in-depth analysis of these questions resulted in the formulation of the following merging schemes: the merging of processes 4 and 5, with a combined operating time of 21.8 seconds; the merging of processes 9 and 10, with a combined operating time of 34.4 seconds; and the merging of processes 15 and 16, with a combined operating time of 28.6 seconds. Following the implementation of these measures, the operating time of each merged process became more uniform with the operating times of the neighboring processes, both before and after it. This effectively balanced the workload of workers and reduced the number of workstations, thereby significantly improving the balancing rate between workstations.

The present study has demonstrated that there was a significant improvement in the production balance rate, which increased from 39.5% to 62.8%. Furthermore, the production imbalance loss rate decreased from 60.5% to 37.2%, and the smoothing index decreased from 42.83 to 18.78. These significant improvements in the key indexes prove the effectiveness and necessity of the optimization measures.

6. Conclusion

In this paper, the authors employed the stopwatch timing method to accurately measure the processing time of the shirt production line, subsequently analyzing the data using 5W1H and ECRS principles. They then proposed an optimization strategy for the original production line, which was characterized by long time-consuming bottleneck processes, inefficient use of equipment, and uneven distribution of workstations. The optimization of the production line layout resulted in a substantial enhancement of the balance rate, a reduction in the balance loss rate, and an improvement in the smoothness index, thereby providing a comprehensive evaluation of the efficacy of the implemented improvements. Following the execution of this enhancement program, there was a notable augmentation in production efficiency and a substantial enhancement in the economic efficiency of the enterprise, thereby providing unequivocal validation of the efficacy of the industrial engineering methodology. In the current market environment, characterized by a proliferation of product varieties and intensified customer demand fluctuations, the utilization of industrial engineering methodologies to achieve efficient production and material turnover of multi-species, small-batch, multi-frequency products has emerged as a pivotal issue that necessitates resolution. This will be the focal point of the subsequent research endeavors.

Disclosure statement

The author declares no conflict of interest.

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