Comprehensive evaluation of garment assembly line with simulation

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Abstract. In this paper, a comprehensive evaluation system is established to assess the garment production performance. It is based on performance indicators and supported with the corresponding results obtained by manual calculation or computer simulation. The assembly lines of a typical men’s shirt are taken as the study objects. With the comprehensive evaluation results, garments production arrangement scenarios are better analysed and then the appropriate one is supposed to be put into actual production. This will be a guidance given to companies on quick decision-making and multi-objective optimization of garment production.

1. Introduction
Sewing, as the longest and most complicated section in garment production process, is crucial to the efficiency improvement in garment industry. In literature, attempts at simulation of garment production process are made, in which computer simulation shows good abilities in obtaining related information [1-2]. Due to those active performances, the way to apply simulation in garment production management which is extensive and closer to the actual production should be put into study in purpose of helping company make decisions economically and efficiently before implementation. For AnyLogic is a java-based simulation software, the corresponding simulate model is of great scalability and extensibility [3]. This study is the first application of Anylogic in garment production simulation. In recent study, key performance indicators (KPI) are put forward for evaluating garment assembly lines and improving their performance [4]. In fact, certain indicators are always taken into consideration together for multi-objectives, and this makes the decision-making much more complex. Facing the demand of multi-objectives in nowadays garment manufacture, a proper scientific evaluation method should be put forward.

The aim of this study is providing support to the decision-making of optional garment assembly line scenarios to achieve multiple objectives in modern clothing production. That is the comprehensive evaluation.

2. Performance indicators
Single performance indicator always reflects certain aspect of the garment sewing line that often cannot fully demonstrate the whole performance. The comprehensive evaluation for garment sewing line is realized through integrating the corresponding performance indicators associated with the
determined objectives to a certain comprehensive indicator to evaluate the performance of the garment sewing line.

Before considering the indicator integration, it is important to figure out what the indicators are and the way to obtain the data.

2.1. Indicators classification
Table 1 shows four main garment production line arrangement objectives and their corresponding performance indicators, also, the solutions for the improvements. In general, the objectives are related to line productivity, line property, product quality and resource cost [1]. As it can be seen, the level of line balance is the key element for improving of the production line performance.

| Objectives                  | Line performance indicators | Solution for improvement |
|-----------------------------|-----------------------------|--------------------------|
| High line productivity      | takt time, line efficiency  | appropriate line balance |
|                             | balancing loss, life cycle  |                          |
|                             | daily output, idle time     |                          |
| Appropriate line properties | workstation number, line   | appropriate line balance |
|                             | scale, resource amount      |                          |
| Appropriate product quality | defective product number    | advanced machine         |
|                             | small probability event     | well-skilled operator    |
| Low resources cost          | resource utilization        | strict defects control   |

2.2. Indicator data obtain
Also is shown in table 1, that part of the indicator values can be obtained via mathematical calculation according with the line balancing results, the others, via computer simulation and modeling.

2.2.1 Manual calculation. Performance indicators which are calculated manually are takt time, line efficiency, balancing loss, workstation number and so forth. Some of them are already known in the process of scenarios designing, like workstation number, line scale, while some are calculated with corresponding formulas mentioned in literatures [5].

2.2.2 Simulation output. Simulations in this paper are conducted with Anylogic, a multimethod simulation modelling tool, developed by the AnyLogic Company (former XJ Technologies). It supports agent-based, discrete event, and system dynamics simulation methodologies [3]. The modelling logic of garment production simulation is established based on the theory of discrete event system [6]. For garment sewing process, source, assembly, service, resourcepool, queue, selectoutput, sink are the selected objects in Anylogic to build the simulation model. Indicator values of life cycle, daily output, idle time and resource utilizations can be obtained according to simulation output.

3. Comprehensive evaluation system
The basic idea of comprehensive evaluation is integrating a plurality of indicators into a single indicator which can reflect the comprehensive condition so as to evaluate the whole performance.

Pre-treatments on the indicator values were done in the light of their characteristics before integration, considering normalizations on aspects of indicators’ type and also the data. The weight coefficient set up rules were generalized based on the assessment objectives and also the characteristics of indicator values. Finally, the pretreated indicators were integrated with the corresponding weights to obtain the comprehensive evaluation indicator to realize multiple-perspective garment sewing production evaluation.

3.1. Indicators pre-processing [7]
Generally, in the light of the preferred direction, for some of the indicators, where the ‘bigger is better’ performance direction applies, for some ‘smaller is the better’, and for the rest, they would better to be closer to certain constant. These indicators belong to three types: maximum type, minimum type, and middle type. Even if they are with the same type, they may have different dimensions or magnitudes. Since these differences can affect the reliability and accuracy of the evaluation results, normalization with both the type and the data of indicators should be done before integration.

3.1.1 Type normalization. To unify the indicators’ types, in this study all indicators are transformed into maximum type by mathematical formulas, so that the larger the comprehensive indicator means the better performance of the garment sewing line.

For middle type indicators, equation (1) can be used, where X’ is the value after type normalization, M is the maximum value of X and m is the minimum value of X. And equation (2) is for minimum type indicators.

\[
X’ = \begin{cases} 
2(X - m) & m \leq X \leq \frac{M + m}{2} \\
2(M - X) & \frac{M + m}{2} \leq X \leq M 
\end{cases}
\]  

\[
X’ = \begin{cases} 
M - X & \text{maximum value of } X \text{ is clear} \\
X^{-1} & \text{maximum value of } X \text{ is not clear}
\end{cases}
\]  

3.1.2 Data normalization. Feature scaling method is applied for nondimensionalization of these evaluation indicators.

In equation (3), X’’ represents the dimensionless indicator value after treatment, M’ is the maximum value of X’ and m’ is the minimum value of X’.

\[
X’’ = \frac{X' - m'}{M' - m'}
\]

3.2. Weights setting

For those objectives are of different importance, the volatilities of the indicator values differ. Before indicators are integrated into the comprehensive indicator, the corresponding weights of the selected indicators are set so as to delimit the intensity of different evaluation indicators on aspect of performance reflection.

In this section, on one hand, considering the importance subjective weight is set based on the "function driven" principle, on the other hand, considering the volatility of the indicator value objective weight is set based on the "discrepancy driven" principle. Then, integrate the objective weight coefficient with the subjective weight coefficient into the comprehensive weight coefficient. [8]

3.2.1 Subjective weight \( \omega_s \). The value of \( \omega_s \) is determined subjectively by decision-making evaluator, where simplified set-valued iterative method is applied:

The importance of the evaluation indicator \( X_i \) (i = 1, ..., k) is determined by evaluator and represented by using natural numbers \( v_i \) (i=1, ..., k). The proportion of the importance of each indicator is then calculated with equation (4).

\[
\omega_s = \frac{v_i}{\sum_{i=1}^{k} v_i}
\]

3.2.2 Objective weight \( \omega_o \). The value of \( \omega_o \) is determined objectively based on the indicator volatility.

The fluctuation range of indicator is determined in line with the difference of extremes to set weight, which is called the range method. As shown in equation (5), the weight is calculated with the maximum value M'' and the minimum value m'' of the pretreated indicator X''.
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\[ \omega_i = \frac{\text{Max}_{j=1}^n (M_i^* - m_i^* \omega)}{\sum_{j=1}^n \text{Max}_{j=1}^n (M_i^* - m_i^*)} \]  

(5)

3.2.3 Comprehensive weight. Through subjective weight set, \( \omega_o \) and \( \omega_a \) are integrated into \( \omega \) as the final comprehensive weight coefficient.

As in equation (6), p, q are two undetermined constants (p>0, q>0 and p+q=1), whose values are determined by the evaluators preference.

\[ \omega = p\omega_o + q\omega_a \]  

(6)

3.3 Comprehensive indicator generation

Evaluation indicators integration is the final step where the linear weight method is applied. This method is also called additive synthesis method, a basic integration method. It uses the weighted mean of the selected evaluation indicator values as the comprehensive evaluation value. It is close to the nature meaning of "comprehensive indicator ". The model is easy to interpret and use, and there is no need to consider the position of a deeper relationship between the indicators. In additional, using overly complex mathematical integration methods will increase the complexity of the comprehensive evaluation and bring negative effects.

In the following equation (7), \( Y \) represents the comprehensive evaluation value, a linear weighted value of \( k \) indicators, \( \omega_i \) is the corresponding weight coefficient of the evaluation indicator \( X_i \). At last, the garment production arrangement scenarios can be evaluated by comparison of the values of comprehensive indicator \( Y \).

\[ Y = \sum_{j=1}^k \omega_i X_i \]  

(7)

4. A case study

In this part, comprehensive evaluation method aided by computer simulation technology is applied in decision-making of a typical men’s shirt production arrangement. Two objectives: line property and resource cost are taken into consideration, especially on aspect of line property, workstation number is the chosen indicator.

4.1. Assembly line design

A typical shirt production is taken as the study object. Basic data like the operation time is collected from the real production in garment factories. Suppose daily output of garments is 400 pieces, effective daily working hours is 7.5h, so the takt time is calculated to be 67.5s [9].

One scenario is arranged basically [9], while in the other scenario, the operation types in each workstation is limited no more than two and if possible just only one. As the results of the assembly line arrangement, the bottlenecks are the same value of 72.5s. The small difference is that the second scenario needs one more workstation but one less machine.

4.2. Data obtain

Regarding the arrangement scenarios, takt time, workstation number and recourse amount are already known. Then the line efficiency and balancing loss are calculated based on the values of takt time and bottleneck [5]. Supposing that the working time is 7.5h per day, a simulation of the state production process for one day with consideration of the setup time is conducted. Suppose there is not small probability event like machine failure, material failure or staff absence. In this case, the simulation related values: daily garment output and resource utilizations are obtained based on 10 times of simulation output.

With the manual calculation and the simulation results, the performance indicators values of these two scenarios are listed in table 2. The differences exist mainly in line property and resources cost.
Table 2. Performance indicators values.

| Aspects             | Line performance indicators | Balancing | Simulation |
|---------------------|------------------------------|-----------|------------|
| Line productivity   | takt time                    | 67.5      | 368/367    |
|                     | line efficiency              | 93.10%    |            |
|                     | balancing loss               | 6.90%     |            |
| Line property       | workstations number          | 16/17     |            |
|                     | line scale                   | 56.32/62.64 |          |
|                     | resource operators           | 29        |            |
|                     | amount machines              | 29/28     |            |
| Resources cost      | resource utilization         |           | 90.58%/90.65% |
|                     | operators utilization        |           | 79.61%/82.53% |

4.3. Comprehensive evaluation

On aspects of line property and resource cost, the workstation number and the resource utilization are the indicators selected to be integrated. The corresponding indicators pre-processing results are shown in Table 3. With the data, two comprehensive evaluations can be done.

Table 3. Performance indicators pre-processing.

| Indicators       | Range     | Normalization formula | X'' | Type | Data | S1   | S2   |
|------------------|-----------|-----------------------|-----|------|------|------|------|
| Workstations     | 10-20     | \( X' = 2(20 - X) \) | \( X'' = \frac{20 - X'}{10} \) | 0.4  | 0.3  |
| Resource utilization Operators | 0-1           | \( X'' = X' = X \) | 90.58% | 90.65% |
| Operators Machines | 0-1             | \( X'' = X' = X \) | 79.61% | 82.53% |

4.3.1 Workstation number and operation utilization. For the value of machine utilization is ranging from 75% to 1, the objective weights are set as follows:

\[
\omega \eta_o(n) = \frac{(1 - 0)/(1 - 0)}{(1 - 0)/(1 - 0.75) + (1 - 0)/(1 - 0)} = 0.2
\]

\[
\omega \eta_o(\eta_o) = \frac{(1 - 0)/(1 - 0.75) + (1 - 0)/(1 - 0)}{(1 - 0)/(1 - 0.75) + (1 - 0)/(1 - 0)} = 0.8
\]

When the importance of these two indicators is set from 10:0 to 0:10, and if both subjective and objective aspects are considered equal, let \( p = q = 0.5 \), the final comprehensive evaluation results of these two scenarios change, which is shown in figure 1.

Figure 1. Comprehensive evaluation results with two indicators: workstation number and machine utilization.

Figure 2. Comprehensive evaluation results with two indicators: workstation number and operator utilization.
4.3.2 Workstation number and machine utilization. For the value of operator utilization ranges from 90% to 1, the objective weights setting results are: \( \omega_0(n) = 1/11, \omega_0(\eta_m) = 10/11 \).

Figure 2 gives the final comprehensive evaluation results of these two scenarios when the importance of these two indicators is set from 10:0 to 0:10 and p=q=0.5.

For these two scenarios, scenario 1 shows a better performance in line property because of the proper workstation number, while scenario 2 shows an obvious advantage in machine cost. Limitation of the operation type does increase resources utilization especially machine utilization, but it will bring more workstations. What is shown in the comprehensive evaluation results for these two scenarios is only when the cost is of much more importance then the production scenario 2 can be selected, or scenario 1 is the better choice.

5. Conclusions

In this paper, performance indicators related to four main objectives are collected. Manual calculation and simulation are the methods proposed to obtain indicator values. Then, the method and process to establish the comprehensive evaluation system and the thought of using comprehensive evaluation method for decision-making in garment production arrangement were put forward in detail. At last, based on the performances of comprehensive evaluation experiment with the classical men’s shirt production lines, guidance about quick and multi-objective selection of garment production scenarios is provided. From the experiment, it can be found that the result is changing when importance of different objectives changes, the comprehensive evaluation can tell which scenario gives a better performance under certain circumstance. Based on the results of comprehensive evaluation, it will be clearer where to put more emphasis and do optimizations. It is proved in this paper that comprehensive evaluation aided by computer simulation does offer help to garment production management.

For future work, emphases will be put on optimizations both in garment assembly line evaluation and simulation. The applicability should be verified with large plenty of actual production situations and use more indicators at one time. Also, based on the existing Java code in Anylogic, maybe it is of great possibility to make attempts at Java code extracting and rewriting to extend simulation models for second development. The extended model can be employed individually and designed to a professional system for certain specific use.

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