Effect of Operator Skill Level on Assembly Line Balancing in Apparel Manufacturing: A Multi-Objective Simulation Optimization Approach

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Abstract

Assembly line balancing problem (ALBP) is defined as assigning work to workstations in order to perform work in a minimum cycle time and to distribute work so as to keep nearly equal utilization of each resource. ALBP is important problems in apparel manufacturing. Apparel manufacturing is man intensive manufacturing environment. In a sewing line, each task should be performed on a standard time (ST). The standard time is the time required to perform a specified task using a prescribed method. Operator Skill level (OSL) has a great effect on the ability of the sewing line to complete jobs on the committed time. A skill operator is this who is able to perform repetitive tasks on the standard time. Due to different OSL, the total completion time of an order quantity is variable. In this paper a shirt sewing line is studied to notice the effect of OSL on jobs completion time. A sewing line is simulated and a multi-objective simulation optimization approach is used to determine the best number of workstations in each group of tasks to minimize work cycle time and to keep nearly the same level of operators utilization. The results show how OSL affects solution of ALBP.

Keywords

Assembly line balancing, Apparel manufacturing, Discrete event simulation, Simulation optimization.

1. Introduction

Sewing of clothing is the operation of joining clothing components together. It is operator based operation. A sewing line consists basically of sewing machines which are used for basic sewing operations. They have different types and can perform different stitches styles such as single-lock stitch machine and over-lock stitch machine, other special purpose machines are also used, such as fusing machines for fusing collar and other components and, machines for sewing button and buttonholes. Sewing is man intensive manufacturing environment. In a standard sewing line, each task should be performed on a standard time. The standard time or standard allowed minute (SAM) is the time required by an average skilled operator, working at a normal pace, to perform a specified task using a prescribed method. A task standard time is calculated by observing operation and applying work study tools. Operator Skill level (OSL) has a great effect on the ability of the sewing line to complete jobs on the committed time. A skill operator is this who is able to perform repetitive tasks on the standard time. So that, due to different OSL at a sewing line, the total completion time of a specific order quantity is variable. Assembly line balancing problem (ALBP) is defined as the subject matter of assigning each piece of work to a workstation (worker or machine or both) in order to perform work in a minimum cycle time and to minimize idle time of all resources. The objective of ALBP is to distribute work so as to keep nearly equal utilization of each resource, meaning that each resource is assigned approximately the same amount of work. ALBP is one of the most important problems is apparel manufacturing. In this paper a busy sewing line is presupposed for study, where the committed finish time of an order is calculated based on task standard time. The objective is to study the effect of OSL on jobs distribution among workstations. Simulation modeling is the techniques of using computer to imitate the operation of real world processes or systems. If a model of a system is simple enough, mathematical models can be applied to obtain exact conclusions about the system being modeled. In case of complex system, analytical methods stands powerless to evaluate such systems which is the case of most real systems. In this situation simulation modeling is applied. ALBP is found to be hard to be modeled analytically. That is why the proposed sewing line is simulated. A multi-objective simulation optimization approach is used to determine the best number of workstations in each group of tasks so as to minimize work cycle time and to distribute work smoothly among workstations by keeping the same level of workstation utilization. Simulation based optimization is the combination of optimization techniques with the simulation model of a system in order to find good responses about the performance of the system. Carlson and Maria (1997) stated that in simulation optimization the interest is sometimes in finding the optimal value for input variables in terms of the system outcomes. One way could be running simulation experiments for all possible input variables. However, this approach is not always practical due to several possible situations and it just makes it intractable to run experiments for each scenario. For example, there might be too many possible values for input variables, or the simulation model might be too complicated and expensive to run for suboptimal input variable values. In these cases, the goal is to find optimal values for the input variables rather than trying all possible values.

2. Literature Review

The aim of balancing assemble lines is to distribute the tasks among workstations so that the idle time of laborers and machines can be reduced, stated Umaranil (2017). Abtew et al. (2019) defined the standard allowed minute (SAM) or standard minute value (SMV) as the standard time for process or operation in standard environment for standard worker, he studied the correlation between SAM and the efficiency of a sewing section to attain sustainable production capacity. Leung Patrick Hui and Sau Fun Frency (1999) studied the effect of time variations of SAM for assemble line balancing. The stated that SAM is generally used in the clothing industry as a predictor of sewing speed and production efficiency. SAM is derived from the work study methods, and there is a lot of factors cause its variations such as the fabrics and sub-materials, performance of the machinery, working environment and quality level of the product. Morshed and Palash (2014) focused on improving overall efficiency of single model assembly line by reducing the non-value added activities, cycle time and distribution of work load at each work station by line balancing. The used methodology calculates the cycle time of process, identifies the non –value-added activities, calculates total work load on station and distribution of work load on each workstation by line balancing. Kara and Atasagun (2013) proposed a binary integer linear mathematical model to solve parallel assembly line balancing with resource dependent task times. Jaganathan (2014) applied Largest Candidate Rule Algorithm (LCR) for line balancing and layout modification. Hanan, and Seedahmed (2019) developed a simulation model which represents real production process scenarios based on balancing U3 Shirt assembly line in Sur Military Clothing Factory. Their model helps to decrease the waiting time, finish time, and increase the efficiency of the line in addition to generating different alternative scenarios to utilize the assembly line. Kitaw et al. developed a simulation model which represent real production process scenarios of garment products that helps to identify the bottlenecks and enhance production system performance. They studied basic polo-shirt manufacturing operation to investigate and demonstrate the application of simulation technique to compare different alternative systems. Simea et al. developed an Arena simulation model to examine five what-if scenarios of work distribution for reconfiguration of an assembly line for a ladies tunic production line. Chen et al. (2012) stated that assemble line balancing problem is known as NP-hard problem , thus heuristic methodologies and simulation can be better ways to plan the sewing lines within a reasonable time. Kursun et al. (2009) used a simulation technique to minimize labor intensity for balancing a sweatshirt sewing line. He mentioned that the apparel manufacturing is labor intensive structure where productivity of workers affects the quantity of output. From this literature it was found that ALBP in sewing is found to be NP hard problem, its solution affects the output of a sewing line and, it can be investigated by means of simulation.

3. Experiment Description

The problem studied in this paper is assembly line balancing of a formal shirt sewing operations. A basic shirt has number of components which are joined together with different types of machines. Flow chart of assembly process is illustrated in Figure 1. The figure shows that shirt making process starts with preparation of its basic components. These components are front, back, pocket, collar, cuff and sleeves. After preparation of each component, they are assembled together to form a shirt. Some of these operations are performed by using a single stitch lock machine (SSL) and others are performed by using over stitch lock machine (OSL). Ironing is needed in some preparation operations. Buttons and button holes machines are also used for attaching buttons and making button holes. Type of machine used and the c time for each operation are tabulated in Table 1. It was obtained from website of online closing study.

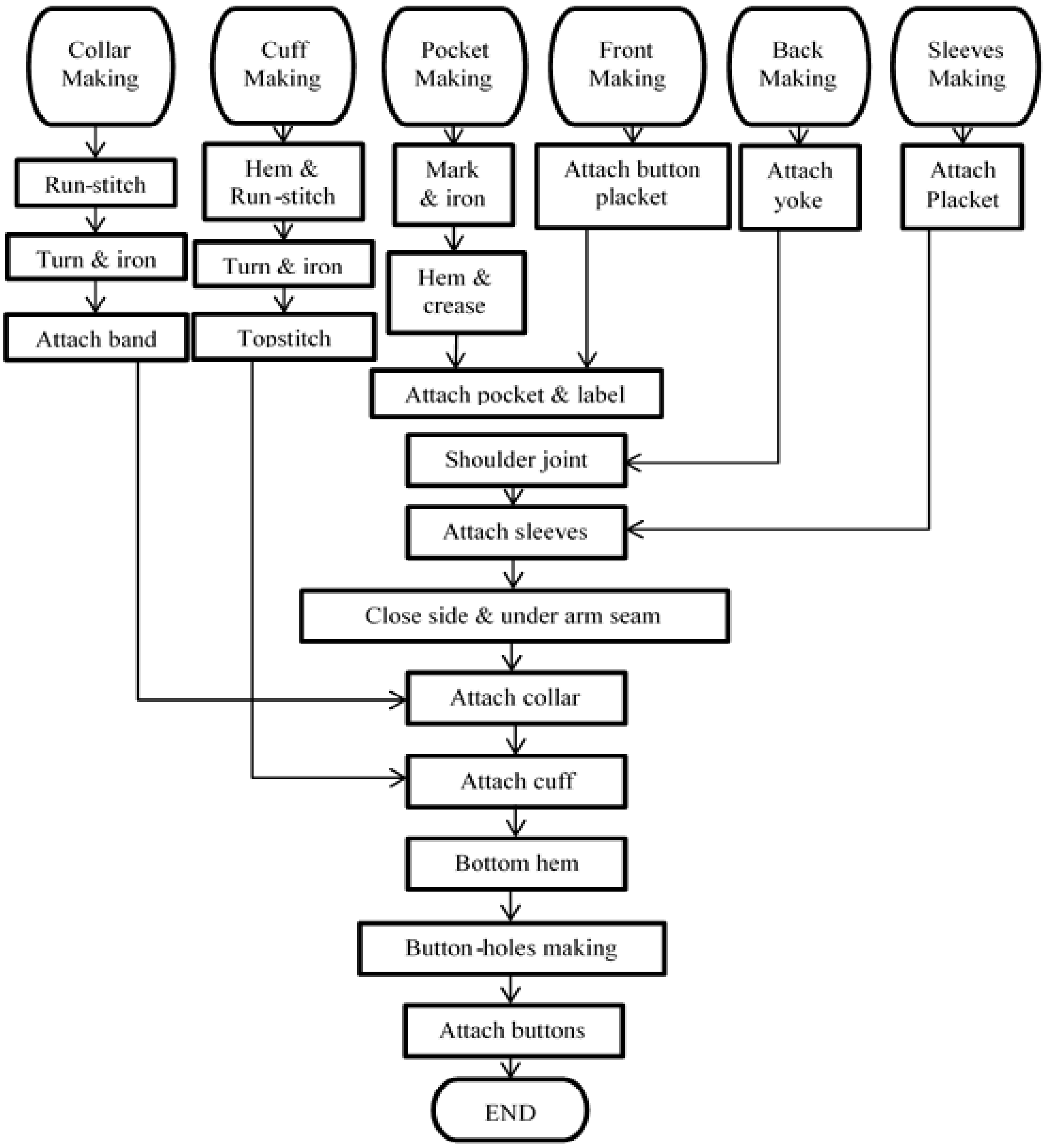

Figure 1 Shirt making process flowchart

The formal shirt sewing line was first simulated by building a discreet event simulation model for it. The Simulation model was developed using Arena™ (a product of Rockwell Software/Systems Modeling Corporation) in a generic way, where each process module represents a sewing operation (workstation) which contains one or more resources. Each resource represents a sewing machine with an operator performing the sewing operation. Twenty boxes of sewing work is required to be operated. Each box contains pieces of the shirts that is enough to make twenty shirts. Completion time of the twenty boxes, the average cycle time of one box and the utilization of each workstation are reported at the end of the simulation run. A screen shoot of the Arena™ simulation model is shown in Figure 2.

Utilization of a workstation is defined as the percentage of time that the resources of a work station are busy doing the sewing operation. Non busy time is the idle time where the workstation has no work to do. Maintenance time is neglected in this study.

Table 1 Types of machines used for each sewing operation and the related standard time

Section name	Operation number	Operation name	Time (min)	Type of machine
Collar Making	1	Collar run stitch	17.6	SSL
	2	Collar turn an iron	6.8	Ironing
	3	Attach ban to collar	35.8	SSL
Cuff Making	4	Cuff hem and run stitch	12	SSL
	5	Collar turn an iron	5	Ironing
	6	Cuff topstitch	11	SSL
Pocket Making	7	Mark and iron	5.2	Ironing
	8	Pocket hem and crease	5	SSL
Front Making	9	Attach button placket	15.6	SSL
Back Making	10	Attach yoke	20.2	SSL
Sleeves Making	11	Attach placket	30.2	SSL
Shirt assembly	12	Attach pocket and label	9	SSL
	13	Shoulder joint	14.8	OSL
	14	Attach sleeves	7.5	OSL
	15	Close side and under arm seam	18.4	OSL
	16	Attach collar	14	SSL
	17	Attach cuff	14.2	SSL
	18	Bottom hem	15.6	SSL
Buttons an button holes	19	Button-holes making	7.4	Button-holes
	20	Attach buttons	8.6	Buttons

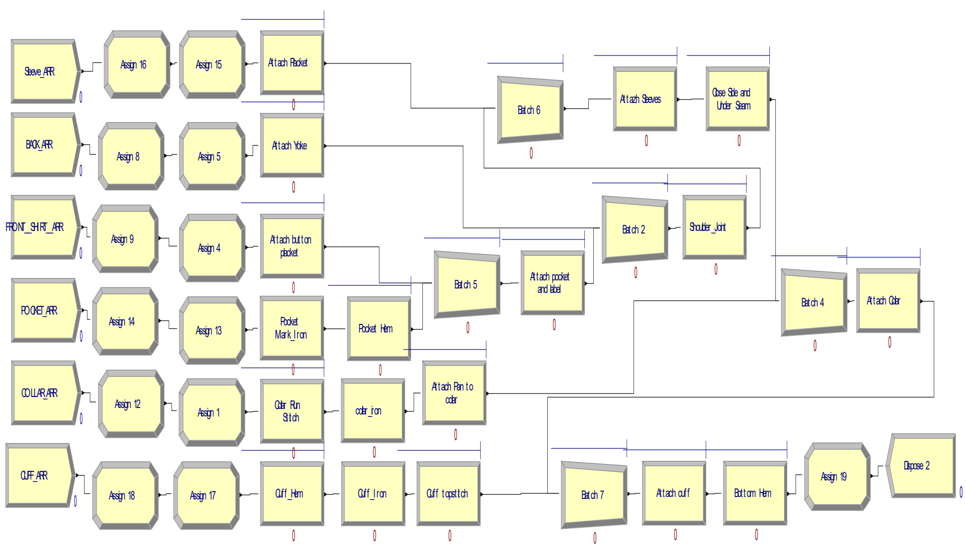

Figure 2 Arena™ model for formal shirt sewing process

3.1. Estimation of OSL

In order to examine the effect of OSL, different levels of OSL distributions is examined. Uniform distribution is selected to express the mean and variability of an OSL, where each instance has the exact same possibility of happening. Four levels of OSL are listed in Table 2. A uniform distribution parameters are lower level x_1 and upper level x_2. Four combinations of x_1 and x_2 are estimated to express different levels of skills of an operator. The first OSL is presented by a skilled operator where lower level is exactly the standard time and the upper level is slightly greater than the standard time. The second OSL expresses an unskilled operator where the upper level is very high relative to the standard time. The third OSL points out a skilled operator that is performing a wrong procedure or not following work steps approved by the work study. The upper level is slightly greater than the lower level but both are shifted above the standard time. The fourth OSL expresses an unskilled operator following the wrong procedure or not following work steps approved by the work study.

Table 2 Different OSL estimations

OSL	x_1	x_2
1	ST	ST + 0.1 of ST
2	ST	double ST
3	1.5 of ST	ST + 0.1 of ST
4	1.5 of ST	double ST

3.2. Simulation Optimization Experiment

In optimum-seeking simulation approach, a general-purpose heuristic optimization engine is interfaced with a general-purpose simulation engine to choose a set of controls that achieves the best value of objective function, Rogers (2002). By determining the objective and the allowable range of values for the controllable parameters, the optimization engine then interacts with the simulation engine iteratively until a final solution is reached. This approach results in a solution which should be "good" rather than optimal (in the mathematical programming sense of provably no worse than the best possible solution), it is referred to as optimum seeking. *OptQuest* is an optimization utility embedded in Arena™. It is a general-purpose heuristic optimization engine that is making use of a combination of the methods of tabu search, neural networks, and scatter search, April et al. (2001). After Arena™ simulation model is built, optimization experiment was conducted using *OptQuest.* The optimization scenario is to find the number of resources at each workstation so as to minimize the completion time for all jobs. Another objective is to equally distribute work among resource so as to keep the utilization of each workstation at minimum of 70% of time.

4. Results and Discussion

The first experiment was unconstrained optimization where it is assumed that there is no limit for the number of resources that can be assigned to any workstation. The objective is to minimize the completion time and to keep nearly equal work distribution. The results showed that the number of resources increased when changing the OSL more than the standard time as shown in Figure 3. The second experiment was constrained optimization where the total number of constrained is restricted to be at maximum of 25 resources. In this case the completion time increased more than that was obtained in the unconstrained experiment. Figure 4 illustrates the completion time for different OSLs for both unconstrained and constrained experiments. All results are tabulated in table 3. It can be noticed that the completion time for the third OSL has been decrease to 9.23 hours. This can be due to the increases number of resources of 40 resources. Numbers of resources for each workstation are listed in table 4 for both constrained and unconstrained experiments. The obtained utilization of all resources is greater than 70%. It can be noticed that the bottlenecks appear at operation number 1, 3, 9, and, 11, where the models seeks to increase the number of resources so as to minimize the completion time.

Table 3 Number of resources and completion time for both constrained and unconstrained optimization experiment

OSL	Unconstrained completion time (hours)	No. of resources	Constrained completion time (hours)
1	7.19	31	9.14
2	10.66	34	12.24
3	9.23	40	19.78
4	15.41	53	25.98

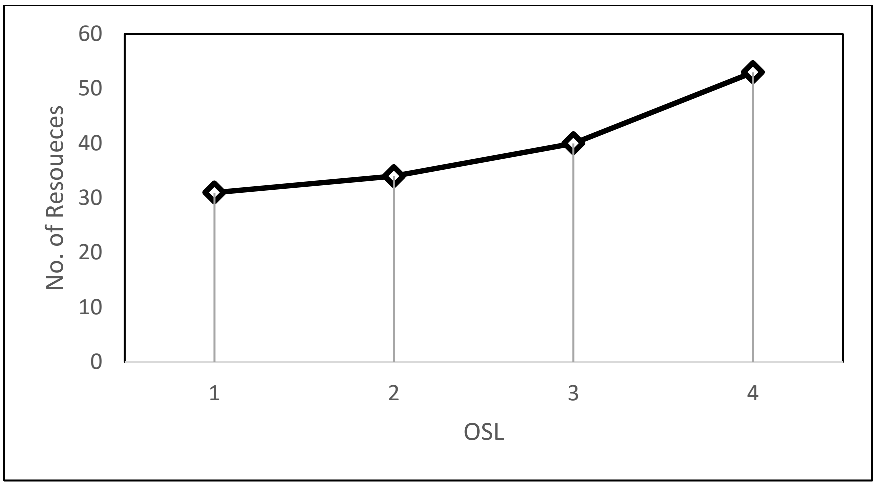

Figure 3 Number of resources for unconstrained optimization

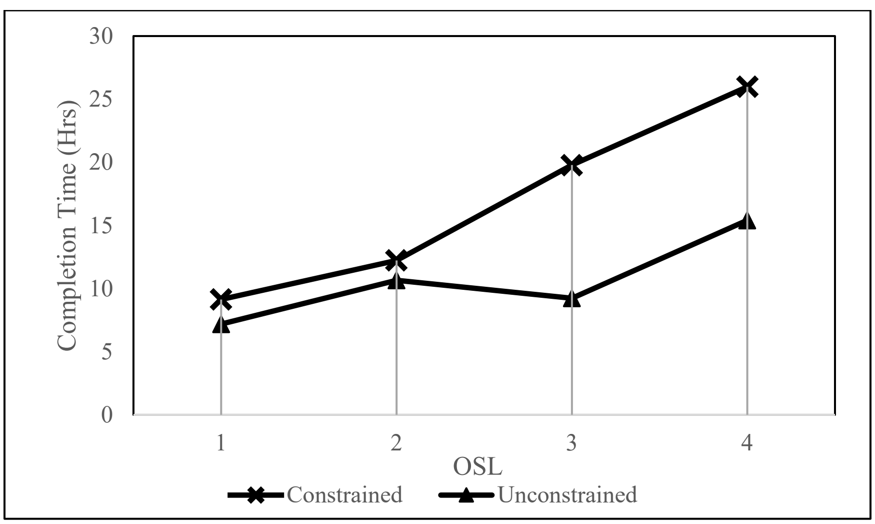

Figure 4 Completion time for both constrained and unconstrained optimization

Table 4 Number of resources for each workstation at each OSL for both Unconstrained and constrained experiments

	Unconstrained Experiment				Constrained Experiment			
Operation number \ OSL	1	2	3	4	1	2	3	4
1	3	2	2	4	1	1	2	3
2	1	1	1	1	1	1	1	1
3	3	3	4	4	2	2	2	2
4	1	3	1	2	1	1	1	1
5	1	1	1	1	1	1	1	1
6	2	2	2	3	1	1	1	1
7	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1
9	3	4	3	4	2	2	2	1
10	2	2	3	4	2	2	3	3
11	3	3	4	8	2	3	2	1
12	1	3	3	2	1	1	1	1
13	2	2	3	4	2	2	1	1
14	1	1	1	2	1	1	1	1
15	2	2	4	4	1	1	2	1
16	2	1	3	5	1	1	1	1
17	1	1	2	2	1	1	1	1
18	1	1	1	1	1	1	1	3

5. Conclusions and Recommendations

In this paper a simulation model for a sewing line was developed. An empirical optimization experiment was conducted to find the best number and distribution of resources to obtain the minimum completion time and maximizing utilization of all resources. Different operator skill levels were examined. The results showed how operator skill level affects the solution of the assembly line balancing problem. Operator skill level affects the completion time of a certain amount of work which leads to affecting the line total output. It also has a great effect on the distribution of work to each workstation

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Biography

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