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Simulation of Production Line Balancing in Apparel Manufacturing

Abstract
To focus on the labour-intensive structure of apparel manufacturing, a sweatshirt sewing line was chosen. To minimise the labour-intensity, the line was balanced using the simulation technique. Firstly, detailed work and time studies were performed along the line. Secondly, to set up a model of the line by simulation, real data taken from a factory floor was tested for distribution fit and a Kolmogrov-Smirnov test conducted for goodness of fit. The data gathered was then transformed into a simulation model. After verification of the model by comparing it with the actual system, bottlenecks in the production line were determined and possible scenarios were tried by various what-if analyses to eliminate the bottlenecks and to suggest decision alternatives to manufacturers. To set up the model, an Enterprise Dynamics simulation program was used.

Key words: *production line balancing, simulation, modelling, apparel.*

Introduction

Over the past 170 years, apparel structure has changed from the custom fitting and assembly of individual hand-sewn garments to the mechanised, automated and sometimes robotised mass production and distribution of ready-to-wear products in the world market. Apparel manufacturing comprises a variety of product categories, materials and styling, and such complexities of manipulating flexible materials and dealing with constantly changing styles limits the degree of automation for the production system. Therefore, when it is compared to many other productions, apparel manufacturing remains labour intensive [1, 2].

When apparel manufacturing is analysed, the central process in the manufacturing is the joining together of components, which is the most labour intensive part of this type of manufacturing, known as the sewing process [3]. Furthermore, when the cost structure is analysed, apart from material costs, the cost structure of the sewing process is of critical importance because of the labour intensity [4]. Therefore, good balancing and small stocks of work in progress during sewing are the basic concepts to increase the efficiency of production [5].

An assembly line is described as a set of distinct tasks that is assigned to a set of workstations connected by a transport mechanism in detailed assembling sequences [6]. In garment sewing, the components are assembled through a sub-assembly process in order to form the finished product. Therefore the production process includes a set of workstations, at each of which a specific task is carried out in a restricted sequence , with hundreds of employees and thousands of bundles of sub-assemblies producing different styles simultaneously [7].

In assembly line balancing, the allocation of jobs to machines is based on the objective of minimising the workflow among the operators, reducing the throughput time as well as the work in progress and thus increases productivity. Up to now, researchers have developed different algorithms to estimate the performance of scheduling [8, 9].

Generally apparel manufacturers are focused on whether assembly work will be finished on time for delivery, finding ways to have more efficiency, how machines and employees are being utilised and how labour intensity can be minimised, whether any station in the assembly line is lagging behind the schedule and how the assembly line is doing overall [1, 10].

Therefore, in order to focus on this kind of labour-intensive structure, a sweatshirt sewing line was chosen for this study. The production line is analysed by considering the innovative use of industrial engineering concepts, time study, assembly line balancing and simulation [11]. Firstly, real data taken from the factory floor using time studies and precedence constraints are taken into consideration to model the allocation of operations to the operators for simulation with the objective of minimising the workflow among the operators. Afterwards with the help of the simulation model of the sewing line, the bottlenecks are determined. Finally, possible scenarios are tried in order to increase the efficiency of the line and to suggest investment strategies to manufacturers.

Experimental

Sweatshirt Production Sewing Line Flow

The whole sweatshirt manufacturing cycle includes a sequence of different phases. In ***Figure 1***, the chronological sequence of assembly operations needed to transform raw materials into a sweatshirt is shown.

Time study

To balance the assembly line production seen in ***Figure 1***. and to suggest investment strategies, a detailed work time study was performed [12].

Since the duration of tasks is dependent on several factors, such as the task, operator fatigue, the properties of fabric and sub materials, working environment,

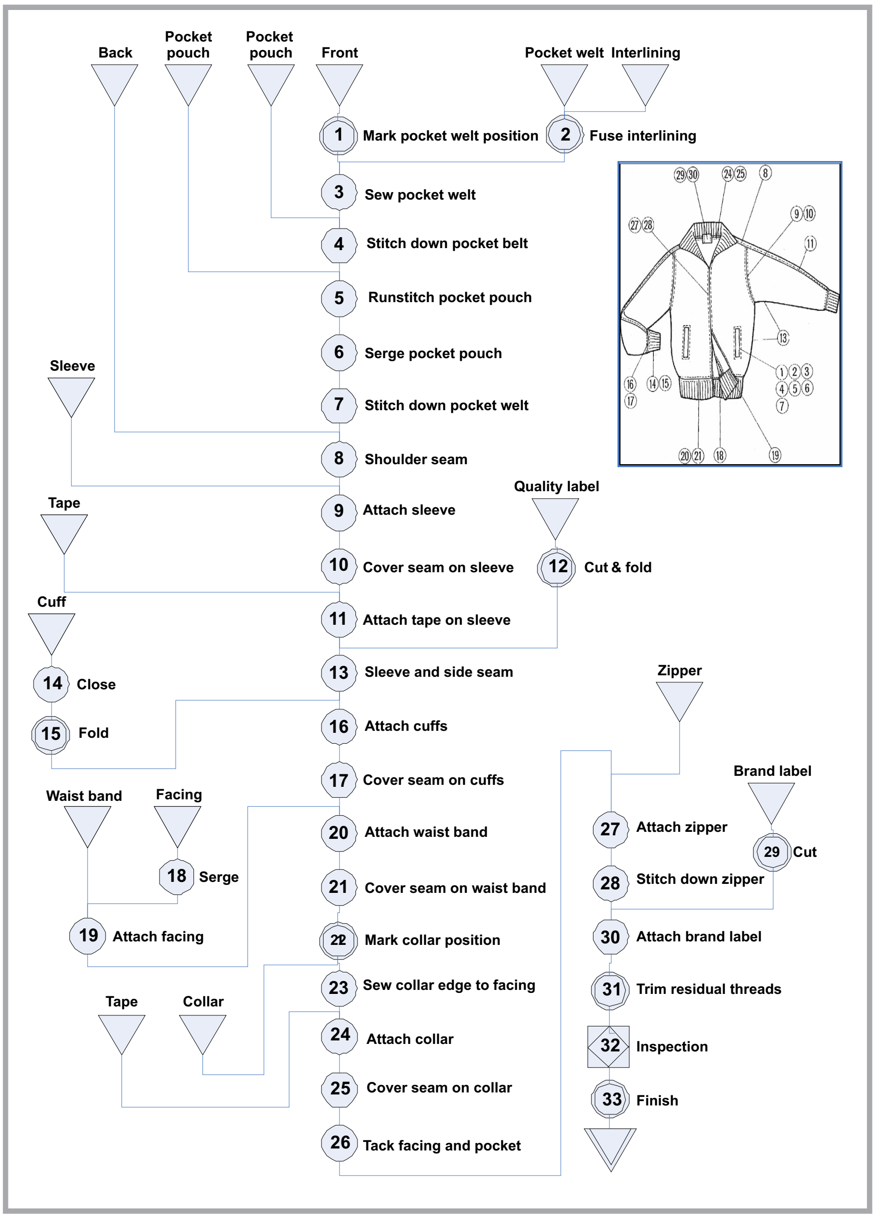

Figure 1. *Flow of a sweatshirt production sewing line.*

Table 1. *Estimated distributions for tasks.*

No:	Task name	Fit distribution, sec	No:	Task name	Fit distribution, sec
1	Mark pocket welt position	Lognormal(8, 1.03, 0.529)	18	Serge facing	Lognormal(11, 0.982, 0.506)
2	Fuse interlining	Uniform(8, 13.)	19	Attach facing	Lognormal(13, 0.957, 0.684)
3	Sew pocket belt	Uniform(20, 29.)	20	Attach waist band	Uniform(25, 35.)
4	Stitch down pocket belt	Uniform(47, 56.)	21	Cover seam on waist band	Uniform(20, 28.)
5	Runstitch pocket pouch	Lognormal(47, 1.18, 0.692)	22	Mark collar position	Exponential(4, 1.85)
6	Serge pocket pouch	Uniform(33, 42.)	23	Sew collar edge to facing	Lognormal(18, 1.43, 0.506)
7	Stitch down pocket welt	Uniform(19, 27.)	24	Attach collar	Lognormal(21, 1.48, 0.508)
8	Shoulder seam	Lognormal(15, 1.49, 0.319)	25	Cover seam on collar	Lognormal(25, 1.65, 0.716)
9	Attach sleeve	Lognormal(30, 1.46, 0.567)	26	Tack facing and pocket	Lognormal(22, 1.85, 0.407)
10	Cover seam on sleeve	Uniform(20, 30.)	27	Attach zipper	Uniform(50, 63.)
11	Attach tape on sleeve	Uniform(20, 30.)	28	Stitch down zipper	Uniform(44, 55.)
12	Cut & fold quality label	Lognormal(2, 0.675, 0.391)	29	Cut & fold	Lognormal(6, 0.675, 0.537)
13	Sleeve and side seam	Exponential(38, 3.35)	30	Attach brand label	Lognormal(7, 1.39, 0.383)
14	Close sleeve cuff	Lognormal(12, 0.9, 0.451)	31	Trim residual threads	Exponential(20, 4.)
15	Fold sleeve cuff	Uniform(11, 21.)	32	Inspection	Lognormal(15, 1.36, 0.661)
16	Attach cuffs	Lognormal(20, 1.58, 0.625)	33	Finish	Uniform(16, 26.)
17	Cover seam on cuffs	Lognormal(25, 1.45, 0.594)			

level of quality etc., in order to calculate the approximate real process time of a task, 20 measurements were taken for each operator working on the line. After data was gathered from the factory floor, it was tested for distribution fit and goodness of fit [5, 13].

Distribution fit and goodness of fit

To estimate the relevant distribution fit of the data gathered, a *Stat::fit Student Version* program was used. For instance, the process 17-Cover seam on a cuff's histogram is shown in ***Figure 2***. The distribution estimated for the process is obtained as *Lognormal (25, 1.45, 0.594)*. ***Table 1*** summarises the distributions estimated for all tasks.

After the estimation of the fit distribution, to validate the goodness of fit Chi Squared test, A Kolmogorov Smirnov test and Anderson Darling test could be applied. While the Chi Squared test is asymptotic, which is valid only as the number of data points gets larger, it might not be appropriate for this study as 20 measurements were taken for each operator. Since the Kolmogorov Smirnov test is not a limited distribution, being appropriate for any sample size, it was chosen to test the goodness of fit in this study. In order to do the tests, an SPSS program was used. The level of significance was set at 0.05 (95% confidence interval) for the Kolmogorov Smirnov test (see Law & Kelton [14], Brunk [15]) and, consequently all the goodness of fit distributions estimated were validated.

For instance, for the process 17-cover seam on cuffs, the asymptote significant (2-tailed) value was evaluated as 0.883, which is greater than the level of significance (0.05) for the Kolmogrov Smirnov test. Thus, the *lognormal (25, 1.45, 0.594)* distribution estimated is appropriate for the input data.

Setting up the simulation model

To set up the model, an *"ENTERPRISE DYNAMICS"* simulation program *Student Version* was used [16]. In the reference factory floor, 33 operators worked on the production line, as seen in ***Figure 1***, and these operators with their machines were placed on the model first. Then the data, as explained in the proceeding section, was transformed into a simulation model for each operator, as shown in ***Table 1***. Also, the interval time of raw material feeding in the system was

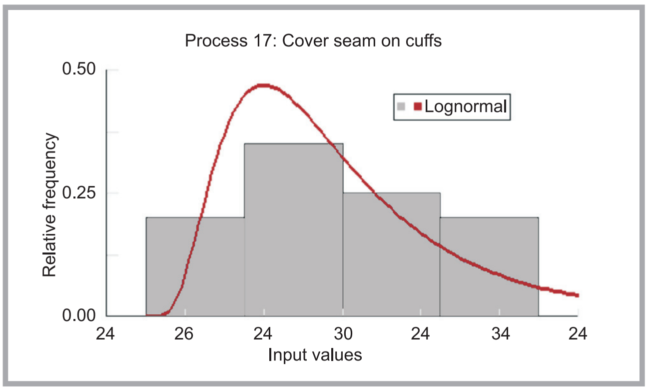

***Figure 2.** Distribution fit of process 17: cover seam on cuffs.*

obtained as an exponential distribution and directly transformed into a model as well. Unfortunately, to analyse the real system and create the model, some conjectures were considered:

- The 8 hour working day of the system.
- Only one worker is at each machine.
- Allowances are not taken into consideration.
- Delay times (machine breakdowns, changing apparatus) are not taken into consideration.
- There is no energy problem in the system.
- Fabric loss is not taken into consideration.
- Raw material is unlimited.
- The supervisor's job on the line was ignored.

By considering the conjectures, the simulation model is run. The model statistics: the number of currents and average content of atoms in the system, cycle time, server utilisation percentage, the stay time of jobs, average output, throughput values of atoms etc., were compared with those of the actual system, and in all cases there was no significant difference between them.

Results

To analyse the results of the system, three performance measures are considered: the average stay times of jobs in queues, the average content of jobs in queues and the quantity of the average daily output . Since our system is an example of a nonterminating simulation, it is evaluated in two stages to consider the effect of the warm-up period . Firstly, to find the warm-up period, the simulation model was run for 800 hours (5 months as a working day) at a 95% confidence level. Nevertheless, with these results, the average output quantity of the system for a day can not be evaluated. To find the quantity of the average daily output, the system was run 100 times, each run consisting of 8 hours of simulated time, taking into account the warm-up period [14].

Results of the reference layout model are summarised in ***Table 2*** according to the performance measures. As seen in ***Table 2***, it can be observed that the average number of finished sweatshirts in a day is 455, the average content of jobs waiting in queues is 90 and the average staying time of jobs waiting in queues is 136 sec. The state diagram of the daily output for 100 observations (5 months) is shown in ***Figure 3***. When these results were compared with those of the actual system, it was also found that the actual system and the reference model results are alike.

To increase the efficiency of the line, firstly the bottlenecks were determined, and then possible scenarios were tried by what-if analysis. As a result three scenarios were developed for the production of sweatshirts.

In scenario 1, one extra sewing machine operator for the 4th process (stitch down pocket belt) was added to the reference layout line. In scenario 2, for the 4th, 5th and 27th processes (stitch down pocket belt, run stitch pocket pouch, attach zipper) one extra sewing machine operator was added to the reference layout line, and in scenario 3, a total of four extra sewing machine operators were added to the reference layout line for the 4th, 5th, 27th, and 28th processes(stitch down pocket belt, runstitch pocket pouch, attach zipper and stitch down zipper respectively). The results for the scenarios are shown in ***Table 3.***

As seen in ***Table 3***, the daily production of sweatshirts is increased to 693 with scenario 3. Also, with the same scenario the average staying times in queues was lower than the reference layout, but the average content of jobs in queues was found to be slightly higher than the reference layout. As far as performance measures are concerned, the first important thing for production is the daily output, which is directly related to the line efficiency; therefore results such as the average content of jobs in queues can be ignored for this reason, but only when they are within acceptable limits.

Furthermore, the results for scenario 3 shows that the system became near balanced after 35 working days by running it for 8 hours at a 95% confidence level (***Figure 4***).

***Table 2.** Results based on reference layout model.*

Performance measures	Average	St. Deviation	L-bound (95%)	U-bound (95%)	Min.	Max.
Daily output	455.48	1.28	455.23	455.73	452.00	458.00
Avarage content of jobs waiting in queues	90.57	0.27	90.52	90.62	90.11	91.35
Avarage staying times in sec of jobs waiting in queues	136.09	0.47	136.00	136.19	134.94	137.50

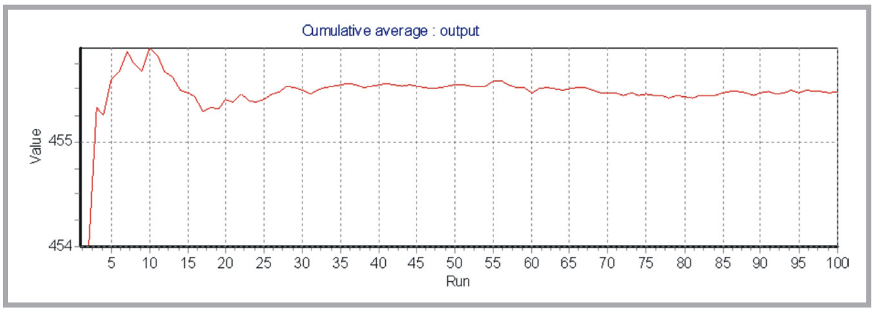

***Figure 3.** Average output of the reference layout per day for 100 observations (5 months).*

Table 3. *The results based on scenarios.*

Scenario	Performance measures	Average	St.Deviation	L-bound(95%)	U-bound(95%)	Min.	Max
1	Daily output	488.83	1.71	488.49	489.17	483.00	492.00
	Avarage content of jobs waiting in queues	102.44	0.99	102.24	102.63	101.06	107.33
	Avarage staying times (sec) of jobs waiting in queues	142.70	1.46	142.42	142.99	140.52	149.53
2	Daily output	565.83	2.67	565.31	566.35	557.00	572.00
	Avarage content of jobs waiting in queues	194.01	2.44	193.54	194.49	185.21	201.72
	Avarage staying times (sec) of jobs waiting in queues	200.19	2.80	199.64	200.74	192.08	209.69
3	Daily output	693.07	7.68	691.56	694.58	659.00	703.00
	Avarage content of jobs waiting in queues	135.63	3.05	135.03	136.23	131.50	151.20
	Avarage staying times (sec) of jobs waiting in queues	132.37	3.74	131.63	133.10	127.32	153.03

Conclusions

In this study a sweatshirt sewing line was considered in order to analyse the labour-structure of apparel manufacturing. In order to minimise the labour-intensity, the line was balanced using a simulation technique. To achieve this, work and time studies were first performed along the line. Secondly, the data gathered was tested for distribution fit, and a Kolmogrov-Smirnov test was carried out for the goodness of fit in order to transform the data into a simulation model. As soon as the data were transformed into a model, verification of the model was done by comparing the model with results for the real system. Then bottlenecks in the line were determined, and three possible scenarios were formed by what-if analyses in order to create a balanced line.

As a result of the study; the daily output of the system is increased to 488 with scenario 1, 565 with scenario 2, and 693 with scenario 3 (up by 7%, 24% and 52%, respectively according to the reference system). Furthermore; the average staying times with scenario 3 is decreased to 132 seconds from 136 seconds. To sum up, with these scenarios the efficiency of the line was increased, and the line was balanced.

These scenarios can provide decision alternatives to manufacturers, but to suggest more comprehensive solution alternatives, the study can be enhanced by a cost analysis of the possible scenarios. Moreover, other major stochastic variables (machine breakdown, repair, absenteeism, the work of the supervisor, maintenance etc.) can be used to detail the model.

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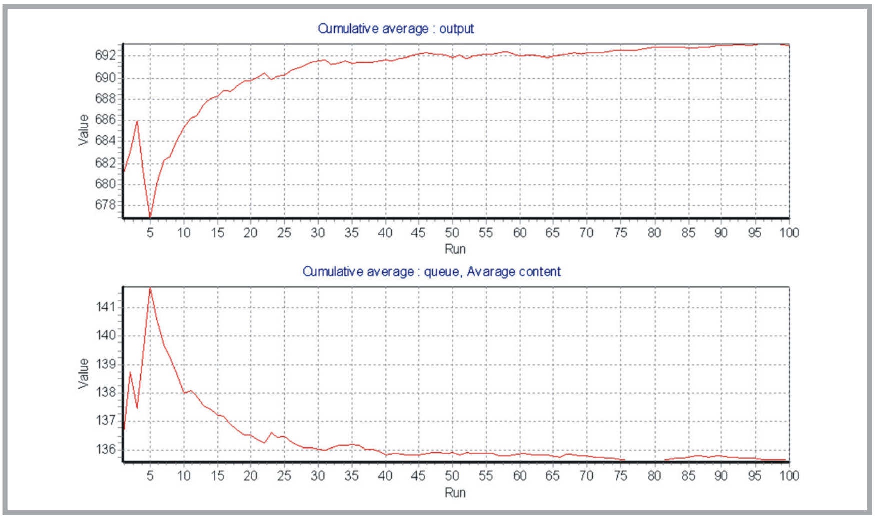

Figure 4. *The average daily output and the average content of jobs in queues for scenario 3 with 100 observations (5 months).*

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