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Productivity Improvement Through Lean Manufacturing Tools: A Case Study on Ethiopian Garment Industry

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Abstract—**Traditionally operated garment industries are facing problems. The problems inherent include longer production lead time, high rework, poor line balancing, lack of standardized work process and performance measurement system for the employee, high work-in-process, low production capacity, high labor (operator) absenteeism, high rework, high fabric waste and poor resource utilization are among others. Adama Garment Industry (AGI), Adama, (Ethiopia) is one of such industries facing these problems. Improving productivity through quantitative research methods and different lean manufacturing tools such as standardization of work process, line balancing, and 5S were used to identify the problems and to address the solutions. By understanding the major problem, the application of these lean manufacturing tools and their benefits were examined. Using time study, the standard allowable minute (SAM) of a military T-shirt model product was fixed to 34.16 min./shirt. After line balancing, the number of labors required to produce equal amount of garment, sewing direct labor cost per production line and per unit and production target is reduced by 24.65% (average),while production capacity, total labor productivity, sewing machine productivity was increased by 30.6% (average), and real line efficiency increased from 55.59% to 83.3%. Similarly, before and after implementation of 5S photographs show improved results, and 41m^2 free areas has been utilized in the cutting section. The implication of this study can provide the complete feasibility report for implementation of lean tools, minimization of waste and effective utilize resource in garment industry for improving productivity. In this study it is recommended to implement full lean manufacturing (LM) tools and to use international standard data as a bench mark for better production system and competitiveness of the garment industry.**

Keywords—productivity; lean manufacturing; benchmark; garment industry; military T-shirt

I. INTRODUCTION

Garment industry is one of the industries that have a potential in developing an economy such as Ethiopia. History depicts that this industry sector has been a base for many successful industrial developments and hence Ethiopian government has defined a policy where one of the tasks identified is rapid export growth through production of high value agricultural products and increased support to export oriented manufacturing sectors such as textile and garment [1]. Garment industries in developing countries are lacking of skilled personnel as well as capital to implement new technologies for improving productivity and flexibility. Because of this, industries have been running in a traditional way for years and are rigid to change. They don't have much confidence and will towards innovation over old processes; hence resulting low productivity and dissatisfaction of customers [2]. Having the same situation part of this problem is facing for Ethiopian garment industry such as Adama Garment Industry, Adama, Ethiopia. The best way to cope with all these challenges is the introducing and practice of lean manufacturing tools [3]. Lean is a term to describe a system that produces what the customer wants, when they want it, with minimum waste. It is based on the Toyota production system or lean production [4]. Lean thinking focuses on value-added lean and consists of best practices, tools and techniques from throughout industry with the aims of reducing waste and maximizing the flow and efficiency of the overall system to achieve the ultimate customer satisfaction [22]. Lean manufacturing is a manufacturing philosophy that shortens the time between the customer order and the product build/shipment by eliminating sources of waste. Another way of looking at lean is that it aims to achieve the same output with less input- less time, less space, less human effort, less machinery, less material, less costs [5]. There are numbers of LM tools when used in proper ways will give the best results [3]. Upon reviewing various literatures, this study is able to identify 28 types of lean tools. The list of some tools are: Kaizen, Kanban, Poke Yoka, Takt time/cycle time, Cell layout, 5S, Visual stream mapping, Ergonomics work, Reduce set up time or Single minute die exchange, Point of use system, Small lot size, Supplier management, Total productive maintenance, Multifunction employees, Uniform workload, Employee involvement, Total quality management, Training, Teamwork, Production smoothing, Work standardization, Visual management, Ishikawa diagram, JIT, Visual displays and control, Operational planning and Six sigma [3, 6, 7, 8].

II. PROBLEM STATEMENT AND RESEARCH OBJECTIVES

AGI is one of the industries corporate under the Ethiopian Metals and Engineering Corporation Industries. The industry is now manufacturing 85% for military and 15% for commercial consumption. It follows a traditional production system. In this industry the process flow layout of garment manufacturing which have interdependency between the cuttings and sewing sections are not properly layout. Also in sewing section the production line is poorly balanced. Sewing operations (with respect to cutting and finishing) needs high skill as well as quality work, because of difficulty associated with repairing of products sewed with wrong specifications [3]. In addition there are other problems faced while garment manufacturing which directly affects the productivity such as: no standard times exist for various production operations and target setting is based on guesswork or experience, and unnecessary movement, low production capacity and poor resource utilization such as space, labor, machine and time. Also there is high worker absenteeism due to the complete absence of attention to this issue high rework and high fabric waste is there. Moreover, in order to achieve a continuous productivity improvement and competitive in the market, it is better to have the industry smart production system (smooth production flow lines). Therefore, the objective of the study is improving productivity through some of lean manufacturing tools for Ethiopian garment industry.

III. RESEARCH METHODOLOGY

This section describes the methodology of this study followed to accomplish its objectives. The initial step in this study was systematically reviewing the related literature such as different tools and techniques of LM system, including standardization of work process, line balancing, and 5S. Also rank positional weight (RPW) has been used for line balancing. Following this the existing production system of AGI was studied using qualitative research approaches [9] for collecting and analyzing the data [10] as a case study. In addition, primary and secondary source of data has been used. Primary data was collected through physical observation and by using stopwatch technique in the shop floor. In the case of the secondary data source, it was obtained through a literature review, internet search related to lean manufacturing and industry technical documents. In this study availability sampling techniques was used. Availability sampling is based on the available chance of the subject during the study [11].

IV. DATA COLLECTION AND ANALYSIS

A. *Work Standardization*

This study consists of conducting time study of sewing operations. By doing this, the sewing operations of single model (military T-shirt) were standardized on single production line.

To compute standard allowable minutes (SAM) of this model:

First, the product was broken down the into nine main operation elements, such as pocket, collar, flap, epaulet, cuff, sleeve, front body and yoke, final assembly and trimming operations. Also these each operation was broken in their sub-operations.

Second, five preliminary samples was taken (hem chest pocket mouth) to determining the number of cycle to be timed the whole process of the model (Table I). The values shown in Table I was calculated as per (1) [12].

$$\bar{x} = \frac{1}{n'}\sum_{x=1}^{n'} x_i \qquad (1)$$

$$\bar{x} = 7.2$$

TABLE I. PRELIMINARY SAMPLE FOR POCKET PREPARATION

Observations	Stop Watch Time, xi (sec.)	Mean of Initial Preliminary Sample, $\bar{x}$ (sec.)	$(x_i - \bar{x})$ (sec.)	$(x_i - \bar{x})^2$ (sec.)
1	7	7.2	-0.2	0.04
2	9	7.2	1.8	3.24
3	6	7.2	-1.2	1.44
4	8	7.2	0.8	0.64
5	6	7.2	-1.2	1.44

Standard deviation and number of observations are calculated as per (2) and (3) [12]:

$$s = \sqrt{(x - \bar{x})^2 \div n - 1} \qquad (2)$$

s=1.304

$$n = (zs \div h\bar{x})^2 \qquad (3)$$

$$n = (2 \times 1.304 \div 0.1 \times 7.2)^2 = 13.10 \text{ cycles}$$

where: n=the number of observation (cycle time) required, n=preliminary sample, x=recorded stopwatch times, $\bar{x}$=mean of initial preliminary sample, s=standard deviation for the initial sample, h=half the precision interval in percent (e.g. if $\pm$ 5%, then h = 0.1), z=number of normal standard deviations needed for desired confidence level. The value of normal standard deviations (z) and half the precision interval (h) were fixed for the reason that most of industries use the confidence level of for 95.5% and correspondence values for z and h are 2 and 0.1 respectively [12].

It is known that any manufacturing processes are different in nature and when the number of observation increases the confidence level increases, thus in this study 24 cycles (observations) were taken in order to get accurate data for the complete garment production processes of the model.

After the performance (PR) is rated at 100% [13], the normal time (NT) and standard time was computed for each task (Table II) by adding the suitable allowances as per (4) and (5) [3].

$$NT = (\bar{x})(PR) \qquad (4)$$

$$ST = NT \div [(1 - A)] \qquad (5)$$

$$ST = 2[23.4 \div (1 - 0.17)] = 56.38 \text{sec.}$$

where: NT=normal time, PR=performance rating, ST= standard time, A=allowance factor.

TABLE II. TIME STANDARD (SEC.) FOR POCKET PREPARATION

Computing of Standard Time Per Piece				
Average Time	*Rating Factor*	*Normal Time*	*Total Allowance*	*Standard Time (sec.)*
Details of elements process:				
Sew chest pocket center:				
23.4	100%	23.4	17%	2×28.19=56.38
Hem chest pocket mouth:				
11	100%	11	17%	2×13.3=26.6
Bottom center sew:				
7	100%	7	17%	2×8.4=16.8
Pocket edge and center press:				
28.7	100%	28.7	17%	2×34.57=69.14
Sum=70.1		70.1		168.92

Total 17% allowance factors for all operations were used viz., personal allowance=7%, basic fatigue allowance=4%, sitting allowance=1%, contingency=5% [3, 13]. Accordingly, as per Table III other operational task time was done in the same way for complete SAM (34.16 min.) of military T-shirt.

TABLE III. SUMMARY OF SAM OF MILITARY T-SHIRT

Main Element Task	SAM (min.)	Main Element Task	SAM (min.)
Pocket preparation	2.81	Sleeve preparation	2.01
Collar preparation	1.7	Front body and Yoke preparation	1.38
Flap preparation	2.7	Final assembly	13.29
Epaulet preparation	2.71	Trimming	4.43
Cuff preparation	3.13	Total	34.16

V. PRODUCTIVITY MEASUREMENT OF MILITARY T-SHIRT

After computing the SAM, productivity has been calculated before line balancing. Similarly, the bottleneck operations of this process were analyzed by comparing with the reference to the calculated maximum cycle time of the existing process. Factors considered during the time study are: the entire available 25 sewing machines in the selected line were fully utilized, no power interruptions, fully supply of materials, fully utilize of 32 labors (no absenteeism), the actual production/day was 250 shirts on the selected line, one shift working hours (8 hours), organization efficiency (η) is 65%, as per the industry scale the average salary/labor (operator and helper) and working day/months were 861ETB and 20 days respectively.

Real line efficiency [21] (L_E) =

$$\frac{\text{Total out put/day/line} \times \text{SAM}}{\text{Total labor/line} \times \text{working min./day}} \times 100 \quad (6)$$

$$L_E = \frac{250\text{shirts} \times 34.16\text{min.}}{32\text{labors} \times 480\text{min.}} \times 100 = 56\%$$

Balancing loss (BL) [18] =(100%-L_E) (7)

B_L =100-56=44%

where: Capacity(hrs)=(Shift hrs/day)×(Total number of labors)

Production target (P_T) =

$$\frac{\text{Totallabor/line} \times \text{working min./day}}{\text{SAM}} \times \eta \quad (8)$$

$$= \frac{32\,\text{labors} \times 480\,\text{min./day}}{34.16\,\text{min./shirt}} \times 0.65 = 292\,\text{shits/day}$$

Total labor sewing productivity =

$$\frac{\text{Total number of units produced/day/line}}{\text{Total labor input/day/line}} \quad (9)$$

$$= \frac{250\,\text{shirts/day/line}}{32\,\text{labors}} = 8\,\text{shirts/day/labor}$$

$$\text{Machine productivity} = \frac{\text{Total number of output/day/line}}{\text{Number of machines used}} \quad (10)$$

$$= \frac{250\text{ shirts/day}}{25\text{ machines}} = 10\text{ shirts/day /machine}$$

$$\textit{Value of DLC} = \frac{\text{Total salary/month}}{\text{Total working days/month}} \quad (11)$$

$$= \frac{861\text{ETB/month} \times 32\text{labors}}{20\text{days/month}} = 1377.6\text{ETB/day}$$

$$\text{Value of } L_C\text{/unit} = \frac{\text{Direct labor cost/day}}{\text{Total output/day}} \quad (12)$$

$$= \frac{1377.6\text{ETB/day}}{250\text{shirts/day}} = 5.5\text{ETB/shirt}$$

B. Line Balancing

Balancing method is very essential to make the production flow almost smoother compare to the previous layout. Considering working distance, type of machines and efficiency, workers who have extra time to work after completing their works, have been shared their work to complete the bottleneck processes. The first step in implementing line balancing is putting precedence relationship between each task activities, which specifies the order in which tasks must, perform. Then after calculated the cycle time (C) as per (13), the theoretical minimum number of workstations or labors (N_t) was determined using (14) that required to satisfy the workstation cycle time constraint using [13].

$$C = \frac{\text{Total time avaliable} \div \text{Period}}{\text{Total output required} \div \text{Period}} \quad (13)$$

C=480min.÷292shirts=1.64min./shirt

To minimize the C the P_T per shift (292shirts/shift) was taken than actual production (250shirts/shift),

$$N_t = \text{Sum of task time (T)} \div C \quad (14)$$

N_t=34.16min.÷1.64min.=20.82 ≅ 21

To assign tasks to workstations for assembly line balancing, a primary heuristics rule which is a RPW has been used. Accordingly, the RPW of operations were calculated as per its procedure mentioned by [14] and are listed in a descending order, as shown in Appendix I. As a result of balancing, it is found that (N=25) workstations are needed to balance the line. This situation is convenient for the condition (N ≥ Nt).

For this assembly line, theoretical line efficiency values (T_E) calculated as per (15):

$$T_E = \sum_{i=1}^{n} T_i \div (N_t \times C) \times 100 \quad (15)$$

$T_E = 34.16 \div (21 \times 1.64) \times 100 = 99.2\%$

The real (actual) line (L_E) efficiency and balancing loss (B_L) of the RPW technique was calculated as per (6) and (7):

$L_E = 34.16 \div (25 \times 1.64) \times 100 = 83.3\%$

$B_L = 100\% - 83.3\% = 16.7\%$

$$\text{Production capacity} = \frac{\text{Capacity in hrs} \times 60\text{min.}}{\text{Product SAM}} \times L_E \qquad (16)$$

Note: As per the RPW technique 21 labors were required to produce 250 shirts per day.

Whereas the production target (P_T), total labor sewing productivity, machine productivity, value of direct labor cost (DLC) and value of LC per unit were calculated by using (8) to (12) consecutively.

Production target (P_T) =

$$\frac{25\text{labors} \times 480\text{min./day}}{34.16\text{min./shirt}} \times 65\% = 228\text{shirts/day}$$

Total labor sewing productivity=

$$\frac{292\text{shirts/ day/line}}{25\text{labors}} = 11\text{shirt/day/ labor}$$

$$\text{Machine productivity} = \frac{292\,\text{shirts/day}}{25\,\text{machines}}$$

=11shirts/day/machine

$$\text{Value of direct labor cost (DLC)} = \frac{861\text{ETB/month} \times 25\text{labors}}{20\text{days/month}}$$

DLC=1076.25ETB/day/line

$$\text{Value of } L_C\text{/unit} = \frac{1076.25\text{ETB/day}}{292\text{shirts/day}} = 3.69\text{ETB/shirt}$$

Hence, changing from traditional layout to balanced layout model, considerable improvements have been found as shown in Table IV.

TABLE IV. SUMMARY OF PRODUCTIVITY MEASUREMENT BEFORE AND AFTER LINE BALANCING

Productivity Variables	Before Line Balancing Output	After Line Balancing Output
Labors per production line	32/production line	25/production line
Production capacity	250/day	292/day
Production target	292unit/day at 65% industry efficiency	228unit/day at 65% industry efficiency
Total labor sewing productivity	8 shirts/labor/day	12 shirts/labor/day
Sewing machine productivity	10 shirts/machine/day	12 shirts/machine/day
Balancing loss	44%	16.7%
Real line efficiency	56%	83.3%
Value of direct labor cost	1377.6ETB/ day/line	1076.25ETB/ day/line
Value of LC/unit	5.50ETB/shirt	3.69ETB/shirt

C. 5S

5S is one of the lean tools and a methodology for organizing, cleaning, developing and sustaining productive work environment. Introducing 5S (Sort, Systematize setting/organizing/stabilizing, Sweep shine/clean, Standardize, and Sustain/Self-discipline) gave everyone the opportunity to learn how to develop and maintain a clean and organized workplace. As part of problem solver this tool was implemented in the cutting section of the garment industry as a model. The reason why this area was selected was due to less busyness in cutting process and has more problem than other sewing and finishing section. Some of the problems in these areas were: poor space utilization, crowded semi-finished fabric not functional spreading machine. Also there was a dirty area, unneeded items stocked between workers, excess inventory on the floor, excess items and machines hindered process flow, improper placement of work in-process fabric and temporary storage tables, no sorting parts, no floor layout, improper material flow and needed equipment, such as tools, is difficult to find. In this sub section it is described that while 5S being implemented in the cutting section (Fig. 1) as a sample.

S1-Sort: All useless things have been sorted and eliminated. In addition, cut and finished fabric has been sorted according to their order number in the cutting section and packing room. Order number labels have been applied to all in-progress and finished fabrics which were mixed during the activity within the temporary storage. The temporary cut fabric storage table, fabric cutting table and the fabric cutting band saw machine have been appropriately arranged. As the result 41m^2 free area has been utilized (Fig.1 b).

Fig.1(a). Before 5S being implemented in the sewing section

Fig.1 (b). While 5S being at the implementation stage in the sewing section

S2-Shine: Dirt, dust, waste fabric and other debris have been removed, floors areas and temporary storage tables have been cleaned, all storing shelves have been cleaned, all machines and tools have been cleaned.

S3-Order: After sorting and cleaning have been accomplished all objects which were placed in their appropriate place and arrangement. The arranging way has been set according to destination and degree of usage. In such case the fabric cutting table and fabric band saw were arranged in "L" shape layouts. In addition for safety working condition work surface borders (fabric cutting table and fabric band saw), floor borders for walkways or aisle ways (trolley), work ways, and storage locations, WIP (cut fabric storage), raw material storage areas have been ergonomically marked using standard colors. In case of 4S and 5S in this section, the workers had been developed a culture of maintain high standards of housekeeping and workplace organization at all times with having habits to practice the above 4S as a way of life.

Fig.1 (c). After 5S being implemented in the sewing section

Fig. 1. 5S implementation photographs

D. Other Wastes that Reduces Productivity

1) Fabric wastage: Saving small pieces of fabric loss from a piece cut can contribute a great role in improving productivity. The important of the cutting process in the garment industry was not over emphasized. Fabric is the most costly portion of any garment content and can be approximately from 50%-70% of the garment cost [15]. Since waste a small quantity of fabric can reduce the profitability of the industry so it should be treated carefully. In AGI there was no any recorded data or control mechanism about the loose of fabric. However, as per the existed production order during the study, to determine the amount fabric wastage in the cutting process, two samples of woven fabric raw material (military uniform and logistic jacket) was taken (Figs. 2 and 3). By considering the number of layers, size of fabric and its weight and as per (17) the amount of fabric loss for sample-1 and sample-2 were 23% and 15.7% respectively.

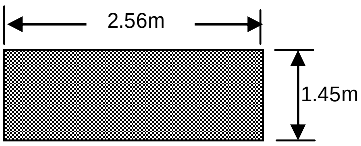

Fig. 2. Sample-1 military uniform (wt. =9.8N, 63 layers, 23%)

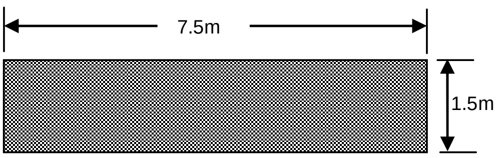

Fig. 3. Sample-2 logistic jacket (wt. =9.8N, 60 layers, 15.7%)

$$\text{The amount of fabric loss } (\%) = \frac{\text{The amount of fabric loss in } m^2}{\text{No. of layers} \times \text{Area of sample/layer}} \quad (17)$$

But the international spreading (cutting) fabric utilization for woven is 8% to 15% fabric waste. Also it was observed that the fabric cutting edge waste was 3cm to 8cm, but the international the spreading waste edge is 2cm to 4cm for both woven samples [17].

1) Rework of process: Rework is one of the main types of waste in lean manufacturing that reduces productivity. Operators do not fix their mistakes but leave them for examiners to find resulting in a high repair level. In this study data was collected for four quarter of recent recorded data (April, 2011-May, 20012) as presented in Table V with higher repair rate (sewing defects found at end line controllers) of some common products in the garment industry. In this case the management could not give an attention to evaluate and how this process can affect the productivity of the industry. The international bench mark for repair work for woven products is less than 2% [17]. But the existing average rework of some woven products of the garment industry was tabulated as in Table V. Certain quality related problems, often observed in garment manufacturing like sewing defects such as: open seams, wrong stitching techniques, non-matching threads, missing stitches, improper creasing of the garment, improper thread tension. Another defect was color defects such as: variation of color between the sample and the final garment, wrong color combinations. And the final another defect often observed were finishing defect such as: broken or defective buttons, missing buttons, unfinished buttonhole, inappropriate trimmings, misalignment of button hole and button.

2) Absenteeism: Absenteeism is another serious problem contributing to low productivity [16]. As per the international benchmark [17], the amount of absenteeism is less than 1%. But the existing value of absenteeism of the labors for six months recorded data (December, 2011-March, 2012) in the garment industry was approximately 10.0%. In addition, the observed average labors absenteeism in 24 days during the production of military T-shirt on production line was 15.62% as shown in Table VI.

TABLE V. AVERAGE REWORK PRODUCTS DATA

Some common products	Total output (pieces)	Total amount rework (pieces)	Rework (%)
Raincoat	1691	162	9.6
Work wear	1563	171	10.9
Military cap	4527	273	6
Shirt (Olive)	1646	118	7.2
Jacket (Logistic)	3101	452	14.6
Military shirt	8710	1084	12.4
Military trouser	3102	226	7.3
Total	24340	2486	68
Average	3477.1	355.1	9.7

TABLE VI. ABSENTEEISM OF 32 LABORS (MARCH, 2012)

Days	Absenteeism per Day (%)	Days	Absenteeism per Day (%)
1	4 (13%)	13	6 (19%)
2	5 (16%)	14	6 (19%)
3	6 (19%)	15	5 (16%)
4	4 (13%)	16	5 (16%)
5	5 (16%)	17	4 (13%)
6	5 (16%)	18	4 (13%)
7	4 (13%)	19	6 (19%)
8	4 (13%)	20	5 (16%)
9	5 (16%)	21	4 (13%)
10	5 (16%)	22	5 (16%)
11	4 (13%)	23	4 (13%)
12	6 (19%)	24	6 (19%)

VI. SUMMARY

This study focused on investigation of the existing problems of the productivity in the garment industry. In other words, this study suggests ways to increase productivity of the industry using some of the LM tools such as: work standardization, line balancing, and 5S.

Accordingly, the finding of the problem in this study is summarized in this manner.

- There is poor line balancing due to lack of time-study or work measurement techniques and shortage of special machine.
- There is bottlenecks process due to unequal work distribution among the workers. During flap and epaulet preparation (run and top stitch), and trimming process are the major problem obtained the bottleneck.
- There is high motion or movement of labors from one workstation to another due to poor line balancing and machine layout.
- There is a high unnecessary transport due to poor material handling.
- There is a high amount of rework due to machine oldness, poor quality thread, labor (operator) absenteeism, complexity of work, fabric color variation, poor cutting process and low operator skill.
- A 24 days continuous observation time study in production line as per the 32 labors absenteeism was 15.62%, but the international bench mark value is less than 1%.
- There is high fabric waste and obtained the average value 19.35% from two sample of fabric, but the international cutting fabric waste for woven is 11.5 %.
- The existing average amount rework of some common woven products is 9.7%. Among these re-work products the logistic jacket has the highest amount of rework rate with 14.6%.
- Neither industry standard data nor international bench mark data which to evaluate operators performance, slow down quality control and efforts to ensure product consistency.

VII. CONCLUSION

The lean principle is a practical approach and low costs of improvement productivity especially for developing country like Ethiopia. The lean management system is based on the continuous loss reduction by means of methods that do not rely on investments, but on the improvement of the processes and the employees' performance. This study has proof the advantages when applying lean tools without sophisticated skill and knowledge to the garment industry and following improvement have been obtained.

- Using work standardization there are considerable improvements the changing from traditional layout to balanced layout model. Sewing operations were standardized by means of time and working procedures, this will help management to know the production target per line and can make the production plan before loading actual products in the shop floor.
- The outputs have been increased to 292 pieces a day with 25 labors which was previously recorded to 250 pieces a day with 32 labors per line. Hence, after line balancing 21 labors are required to produce equal amount of pieces per line in a day.
- Using 5S in the cutting section a 41m2 areas has been utilized, cleaned and attractive working area has been created, floor borders for walkways or aisle ways (trolley), WIP storage locations and raw material storage areas have been marked using standard yellow colors. Also the WIP parts (cut fabric) has been sorted and coded with batch number.

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Appendix- I [20, 23] (as per Appendix-II and III)
Balancing Results of RPW Technique for Cycle Time (C) of 1.64 Minutes

Work Stations (N)	Task Number	RPW Value	Precedence Relations	Operation Time (min.)	Cumulative Work Time (X) min.	Remaining Time (C-X) min.
1	1	20.35	-	0.75	0.75	0.89
	9	20.19	-	0.80	1.55	0.09
2	2	19.6	1	0.85	0.85	0.79
	10	19.39	9	0.43	1.28	0.36
	5	18.99	-	0.35	1.63	0.01
3	11	18.96	10	0.31	0.31	1.33
	3	18.75	2	0.92	1.23	0.41
4	12	18.65	11	1.27	1.27	0.37
5	6	18.64	5	0.53	0.53	1.11
	7	18.11	6	0.46	0.99	0.65
	4	17.83	3	0.18	1.17	0.47
	8	17.65	3, 7	0.27	1.44	0.2
6	13	17.38	8, 12	1.00	1.00	2x1.64-1=2.28
	18	17.31	-	0.75	0.75	2.28-0.75=1.53
	19	16.56	18	0.99	0.99	1.53-0.99=0.54
	14	16.38	13	0.53	1.52	0.54-0.53=0.01
7	15	15.89	-	0.04	0.04	1.60
	16	15.85	14, 15	0.64	0.68	0.96
	22	15.76	-	0.58	1.26	0.38
8	20	15.57	19	0.97	0.97	0.67
	17	15.51	16	0.61	1.58	0.06
9	23	15.18	22	0.66	0.66	0.98
	21	14.6	17, 20	0.54	1.20	0.44
11	24	14.52	23	0.46	0.46	1.18
	27	14.15	-	0.67	1.13	0.51
12	25	14.06	21, 24	1.21	1.21	0.43
13	28	13.48	27	0.88	0.88	0.76
	26	12.85	25	0.71	1.59	0.05
14	29	12.6	28	0.23	0.23	1.41
	30	12.37	29	0.23	0.46	1.18
	31	12.14	26, 30	0.99	1.45	0.19
15	35	12.08	-	0.37	0.37	1.27
	36	11.71	35	0.61	0.98	0.66
16	32	11.15	31	0.98	0.98	0.66
	37	11.1	36	0.61	1.59	0.05
17	33	10.17	32	0.85	0.85	3.28-0.85=2.43
	38	9.98	37	0.86	1.71	2.43-0.86=1.57
	34	9.32	33	0.37	2.08	1.57-0.37=1.2
	39	9.12	38	0.17	2.25	1.2-0.17=1.03
19	40	8.97	34, 39	1.05	1.05	0.59
20	41	7.9	40	1.11	1.11	0.53
21	42	6.79	41	1.18	1.18	0.46
22	43	5.61	42	1.18	1.18	0.46
23-25	44	4.43	43	4.43	4.43	4.92-4.43=0.49

Appendix II. Precedence data of Military T-shirt [12, 19]

Task number	Task descriptions	Task time (min.)	Task that must precede	Task number	Task descriptions	Task time (min.)	Task that must precede
1	Run stitch	0.75	-	23	Turn and press	0.66	22
2	Turn (hand)	0.85	1	24	Top stitch	0.46	23
3	Top stitch	0.92	2	25	Collar attach	1.21	21, 24
4	Button hole	0.18	3	26	Collar top stitch	0.71	25
5	Over lock (yoke, back and front)	0.35	-	27	Sleeve loop attach	0.67	-
6	Turn and pressing (front) × 2	0.53	5	28	Top stitch	0.88	27
7	Button hole (front) × 5	0.46	6	29	Loops tuck	0.23	28
8	Flap attach (R and L)	0.27	3, 7	30	Over lock	0.23	29
9	Sew chest pocket center	0.80	-	31	Sleeve attach (L and R)	0.99	26, 30
10	Hem chest pocket mouth	0.43	9	32	Sleeve top stitch (L and R)	0.98	31
11	Bottom center sew	0.31	10	33	Side seam (L and R)	0.85	32
12	Pocket edge and center press	1.27	11	34	Turn and trimming (hand)	0.37	33
13	Pocket attachment (L and R)	1.00	12, 8	35	Hem run stitch	0.37	-
14	Flap top stitch (R and L)	0.53	13	36	Inner run stitch	0.61	35
15	Back and yoke over lock	0.04	-	37	Turn and press	1.12	36
16	Shoulder attachment (L and R)	0.64	15, 14	38	Top stitch	0.86	37
17	Shoulder top stitch (L and R)	0.61	16	39	Button hole	0.17	38
18	Run stitch	0.75	-	40	Cuff attach (L and R)	1.05	34, 39
19	Turn (hand)	0.99	18	41	Bottom hem	1.11	40
20	Top stitch	0.97	19	42	Mark button hole position	1.18	41
21	Epaulet attach (Land R)	0.54	17, 20	43	Button attach	1.18	42
22	Run stitch	0.58	-	44	Trimming	4.43	43
					SAM	34.16	

Appendix III. Element precedence diagram [18, 23]