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LEAN APPLICATIONS TO IMPROVE CHEMICAL LABORATORY PRODUCTION CAPACITY IN THE TEXTILE INDUSTRY

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Abstract

Lean literature suggests that the attitude of "wait and see" has not yet allowed textile professionals to adopt Lean in production, especially in the laboratory. To fill this gap, the author illustrated a case study in a chemical laboratory of a renowned knit composite industry in Bangladesh. A team of textile and industrial engineers observed all processes in the laboratory from start to end for two years to detect problems and then conducted four brainstorming sessions with Lean experts to generate solutions to those issues which are finally presented for capacity improvement through dyeing machines' capacity optimization, lead time evaluation, lab room temperature optimization, facility layout redesign, quick worksheet preparation, and workplace organization. This study proves that Lean applies to any process improvement. Also, data obtained in this research is highly valuable for textile engineers for future research and readily available for Value Stream Mapping.

Keywords: *Lean production; production capacity; lead time; chemical lab; textile industry.*

1 INTRODUCTION

History suggests that Bangladesh, previously known as East Bengal, was self-sufficient in textiles; and in the eighteenth century, its people produced Muslin, Jamdani, and various cotton and silk fabrics so well that after the growth of mechanized textile mills in the English Midlands, according to popularly held beliefs, the British imperialists responded to the competition for their emerging textile industry by cutting off the thumbs of the craftsmen to force them to stop production (Islam et al., 2013). Now, Bangladesh, a developing market economy (Riaz & Rahman, 2016), is ranked the 39th largest in the world in nominal terms, and 29th largest by purchasing power parity; and is classified among the "Next Eleven" emerging market middle-income economies and a frontier market. In the first quarter of 2019, Bangladesh is the world's seventh fastest-growing economy with a rate of 7.3% real GDP annual growth (Real GDP Growth, 2019). The main source of this rapid growth is the textile and clothing industries. Bangladesh has become the world's second-biggest exporter of clothing (Latifee, 2016) with US$28.14 billion in the financial year 2016-2017, which was 80.7% of the country's total export earnings and 12.36% of the GDP (Latifee, 2017).

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To face "global competition, uncertain demand environment, and higher consumer expectations", companies are adopting Lean to build "manufacturing systems characterized by having high-velocity order-to-delivery and flexible processes which improve the overall business performance" (Deif & ElMaraghy, 2014). Now some developed countries like Germany even started to think about industry 4.0 applications blended with Lean in the textile industry (Kuesters et al., 2017); but with a decade's close observation of apparel industries in Bangladesh, the author has found that although garmenting (cut-sew-pack) areas have got huge attention from the Industrial Engineering (IE) and Lean point of view from 2000 and 2005 respectively, the fabric side has remained totally out of focus.

For fabric production in the textile industry, the chemical lab is the place where the first step is performed. The main recipe of the dyeing is developed here to ensure the desired shade of fabric for bulk production. Generally, the process is performed on 10 grams of fabrics or 5 grams of yarn. The initial recipe is developed from the spectrophotometer based on the buyer's given standard specifications. Following the initial recipe, different samples are developed to match the desired shade of the fabric. If the matched sample is approved by the buyer, the respective recipe is used in the bulk production of the dyeing operation. In the chemical lab, different processes are performed to develop the sample, such as preparing the recipe; preparing the dye stock solution; preparing the worksheet according to the solution, dyeing process, hot and cold wash, soaping, squeezing, drying, conditioning, and sample assessment, etc.

2 LITERATURE REVIEW

According to the Institute of Industrial Engineers: IE is "concerned with the design, improvement, and installation of integrated systems of people, material, information, equipment, and energy. It draws upon specialized knowledge and skills in the mathematical, physical, and social sciences together with principles and methods of engineering analysis and design to specify, predict and evaluate the results to be obtained from such systems" (Salvendy, 1992; Dastkhan & Owlia, 2009).

"Lead time is the amount of time that passes from the start of a process until its conclusion. Companies review lead time in manufacturing, supply chain management, and project management during pre-processing, processing, and post-processing stages. By comparing results against established benchmarks, they can determine where inefficiencies exist" (Kenton & Abbott, 2019). Even value-added (VA) activities are not expected to be performed inefficiently, VA activities are the work that the customer is willing to pay for (Beels, 2019). "In processing operations, the value-added activities are those that make physical changes to the raw material up to finish product" (Islam, 2019) and the work also needs to be done right the first time (RFT). On the contrary, non-Value added (NVA) activities just consume resources without adding any value to the product or service (Beels, 2019).

Lean production (LP), a philosophy to improve performance in production systems by eliminating waste and delivering value for customers, has already been proven with empirical evidence of benefits in terms of lead times, productivity, quality, and other business dimensions (Soliman & Saurin, 2017). It is characterized in short by "doing more with less". "Lean philosophy focuses on the elimination of waste and excess from the tactical product flows and represents an improvement and sometimes an alternative model to that of capital-intensive mass production with its large batch sizes, dedicated assets and hidden wastes" (Deif & ElMaraghy, 2014). "Womack and Jones (Wong & Wong, 2011) define waste as any human activity which absorbs resources but creates no value. 'Muda' is a Japanese word for waste and Ohno (Lewis, 2000) has identified seven types of waste which are also known as Ohno's seven Muda. They are overproduction, waiting, transportation, unnecessary motion, inappropriate processing, and defect. Waste is always linked to lean. But later, the eight wastes have been added to Ohno's original list by other authors, namely as "underutilized people". However, Liker (Goodson, 2002) uses a different term for the same type of waste which is known as "unused employee creativity'" (Wahab et al., 2013).

Lean methodology like '5S' helps to organize the workplace by removing items that are no longer needed, setting the necessary items to visualize wastes, cleaning the work area, and developing behaviors to keep the workplace organized over the long term. A lean system like Kanban is used "to control and create lean production without delays. The system compares supply with current consumption. A message tells the provider to manufacture and deliver another batch. That system works in a cycle connected between the supplier, producer, and buyer" (Zapara & Naumova, n.d.). Kanban's act as the nerve of any Just-In-Time system as a means of material transportation and production information exchange between workstations (Jothishankar & Wang, 1992).

In this study, the author investigated IE and lean implementation status in a chemical lab – Is the lab production going on as per capacity? Is the lab room temperature set for fast production? Are processing time, waiting time, lead time, etc. known to lab managers? Is the room layout designed for efficient production? Is the Worksheet being prepared in efficiently? Is there any production planning activity? And if there any workplace organization practices it in place?

3 METHODOLOGY

According to the researcher (Islam, 2019), a case study is a systematic inquiry into a group of related events to describe and explain the phenomenon of interest. Usually, it is used prospectively but, in this research, it is applied retrospectively (Zucker, 2009). The main reason for selecting the case study method is that it is the preferred method when attempting to answer "why" and "how" research questions about events over which the researcher has no control (Yin, 2017).

After checking a dozen of large textile industries in Bangladesh, the researcher selected the most renowned and best customer-oriented high-volume company for the case study. The company has two fabric units with two chemical labs working on three types of fabric/yarn construction: 100% cotton; 50% cotton & 50% polyester; and 100% polyester are used. Data was collected from direct observations and participant observations" (Yin, 1994; Islam, 2019). A point-to-point observation was planned to perform during this research. Every movement and activity of an individual employee was observed during the operation as well as recorded the time consumed during that period using a stopwatch. The author himself remained stood up in the lab and followed the workflow. Three batches were followed individually from the first activity to the last activity as per the below form in Table 1.

Table 1 Data Collection Form

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Time Duration (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks

After observing the current condition of the chemical laboratory, the researcher decided to perform some analytical and situational observations to analyze the current situation and assess the current capacity. To remove non-value-added activities and to propose improvement suggestions based on Lean concepts, brainstorming sessions were conducted. Brainstorming is a group process used in a variety of applications in quality and reliability work to generate a diverse set of original ideas, approaches, theories, or points of view (Plesk, 2008). The researcher worked as both team leader of the group and "head cheerleader" while the participants discussed that hard work in a team-based engineering environment would be personally rewarding to everyone concerned (Payton, 2005). Participation of production personnel was highly encouraged. The sessions were done in two distinct stages, "first a 'brain dump' for rapid idea generation and verbalization" (Hartman, 2005) with no evaluation to ensure the complete flow of ideas (Sloane, 1998). In the second stage, the ideas were addressed collectively as themes and/or individually as ideas within themes (Claxton, 1980) and evaluated "in terms of expense, workability, practicality, and feasibility given the resources available" (Boddy, 2012).

4 DATA AND RESULTS

4.1 Capacity Utilization

Tasks in a chemical lab in the textile industry are mixed with manual and machine-based activities. Although the design run time per machine per day of three shifts in 24 hours is 1440 minutes, for highly manual (by hand) tasks the allowance time usually ranges from 15 to 25% (Tanvir & Ahmed, 2013), where personal needs consist of up to 5% for men and 7% for women: restroom, smoking, drinking water, lunch, etc.; and basic fatigue: energy spent during working consists of 4%. Instead of just taking 10% allowances without recording and considering any delay (Starovoytova, 2017), this study followed that any delay/time spent as low as 8 seconds would be recorded appropriately (Ackerman et al., 2014) and on top of that 15% allowance was considered to improve the credibility of the results. The effective run time of the machine is also considered 15% less than the designed run time which is 1440 min per whole day of 3 shifts of 8 hours each.

Working time per day per machine = 1440 minutes - Allowance 15%
= (1440 – 216) minutes
= 1224 minutes

The researcher analyzed 500 samples of different batches of 100% cotton; 50% cotton & 50% polyester; and 100% polyester. On average, five trials of shade were required to develop a sample. With 12 beakers per run and five shades per batch, the summary of the capacity analysis is presented in Table 2. From the acquired data, no. of development of approved samples per day in August 2019 was found as 33. Hence, for that month Dyeing Machines' Capacity Utilization was 51%.

Table 2 Capacity of dyeing machines

Fabric/yarn type	Maximum observed time (minutes) per batch	Batch capacity per machine per day	Batch capacity of 7 machines per day	% of customer orders	Average batch capacity per day
100% cotton	112	10.93	76.5	70%	65
50% cotton & 50% polyester	227	5.39	37.7	20%	
100% polyester	216	5.67	39.7	10%	

4.2 Room Temperature Optimization

The case study company has two chemical labs in two fabric units (FU) and these labs were maintained at two different room temperatures: 23.5°C and 28.0°C in FU-1 and FU-2 respectively. The ventilation and air conditioning machine was not efficient in FU-2, that's why it got hotter than the outside natural temperature. As a result, dyeing times for the same programs were found different in FU-1 and FU-2 as given in Table 3. The total non-value-added time for three observations was found 24 minutes in the FU-1 lab and 94 minutes in the FU-2 lab. On average per observation, the FU-2 lab took 23.33 minutes more than the FU-1 lab only due to high room temperature. So, by just maintaining a better room temperature of 23.5°C in FU-2, even with the highest dyeing time of 227 minutes per batch, 770 minutes were saved from 33 batches per day. Now FU-2 can produce three more batches each day.

Table 3 Comparison of temperature facts in two labs

FU-1 Room Temperature: 23.5°C				FU-2 Room Temperature: 28.0°C			
Obs. No.	Program time (minute)	Actual Working Time (minute)	NVA Percentage	Obs. No.	Program time (minute)	Actual Working Time (minute)	NVA Percentage
1	76	84	10.52%	1	90	112	24.40%
2	142	147	3.53%	2	110	140	27.27%
3	141	152	7.80%	3	130	172	32.30%

4.3 Lead Time

Each working process of the 3 types of fabric/yarn was structured into 17-24 sub-processes and further detail of each activity in a sub-process was studied for two years. The movement of the working personnel was carefully observed from the beginning to the end of the operation in both the cases of performing manually and using the machine. Through rigorous discussion, three batches were selected as suitable/representative for further analysis. Data in detail - Activity, Activity Type, frequency, Dependency, Time Duration, Distance Travelled, Parallel Activity, Waiting Time, Responsible person, and Remarks are presented in Appendix A, Appendix B, and Appendix C. Data summary of the five batches are presented in Table 4.

Table 4 Data summary of five selected batches

Obs. No.	Fabric/ Yarn Type	No. of beakers	Total Process	Total Sub-Process	Lead Time (Min)	Processing Time (Min)	Waiting Time (Min)
1	100% Cotton	14	17	47	311.07	268.72	42.35
2	50% Cotton & 50% Polyester	4	20	55	290.50	281.45	9.05
3	100% Polyester	19	18	50	378.82	341.87	36.95

A different batch contained different numbers of beakers per batch based on situational management, also a different number of processes and sub-process. As a result, the total time required to complete any batch was also differing. The average lead time for a batch was found 326.80 min while the average VA (processing) time was 91%.

4.4 Facility Layout

Through some brainstorming sessions, a new layout is developed to minimize transportation and free space. The old and new layouts are given in Fig. 1 and Fig. 2 respectively. From the new layout, it can be inferred that the distance between the spectrophotometer and the management table was reduced by 360 cm. The reduction of this distance helped the management personnel to collect the document of buyer standards from the management table and to transfer it to the spectrophotometer table in a shorter time. But the frequency of this activity was high. Hence, lots of time was saved.

As an overall result, the new layout requires smaller floor space for production. In the previous place of the spectrophotometer, a machine (approx. 42.5 square meters) can be placed and in between two data storing racks, sufficient space is free to place two more dyeing machines (approx. 8.52 square meters) which helps to improve and balance the capacity of the chemical laboratory.

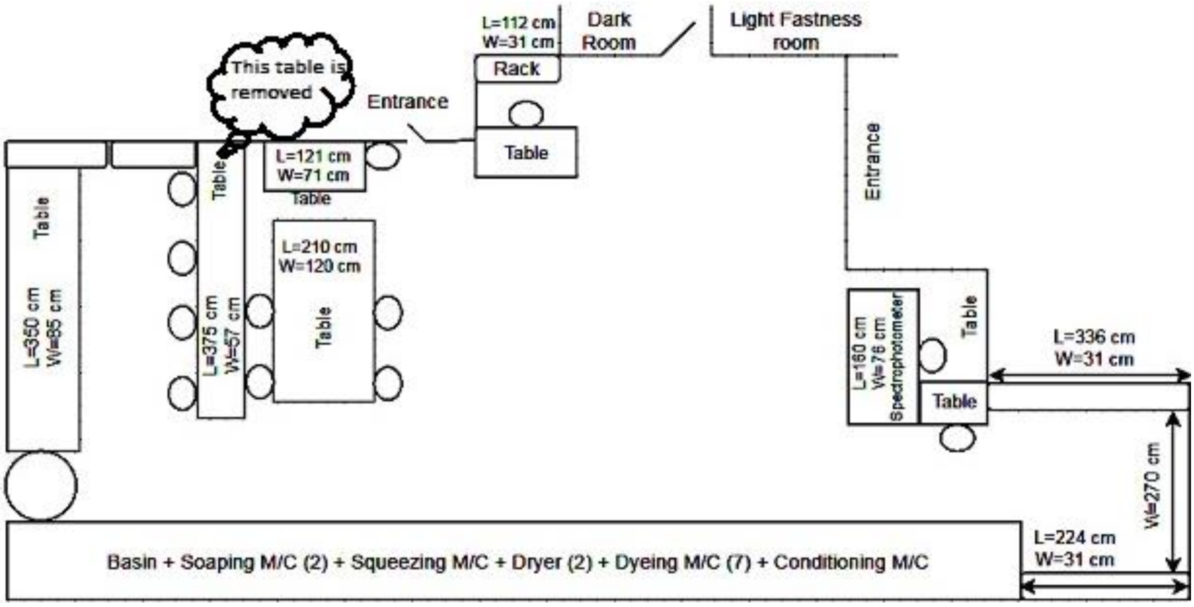

Fig. 1 Old Layout *Source: Author's creation*

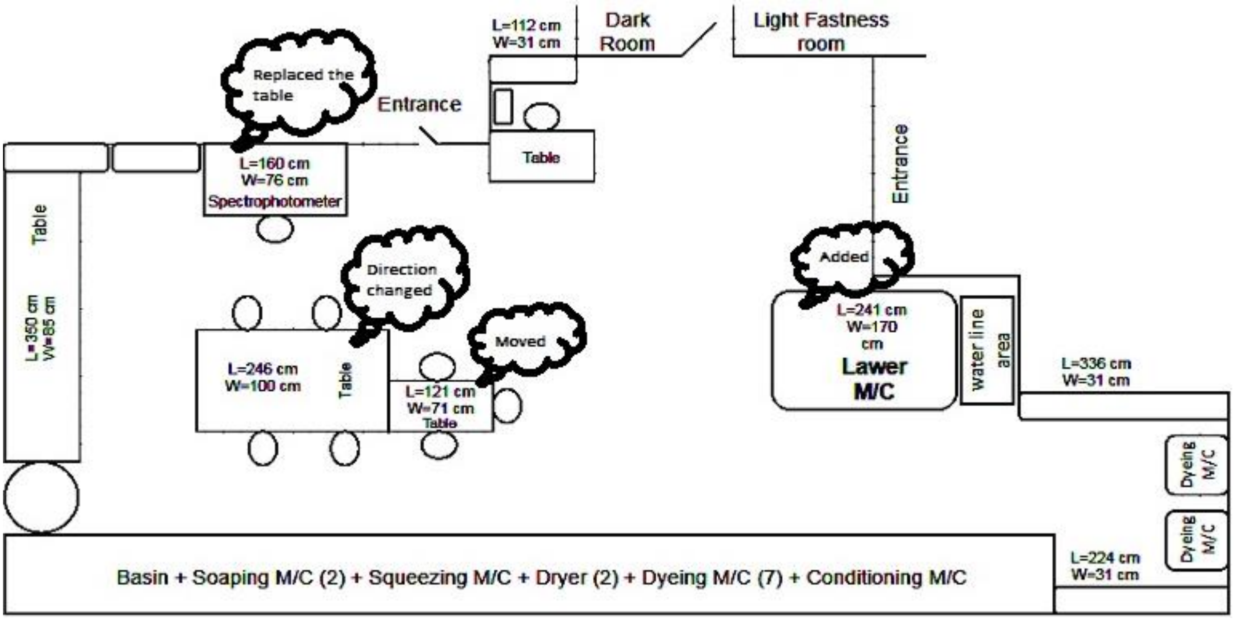

Fig. 2 New Layout *Source: Author's creation*

4.5 Worksheet Preparation

According to the buyer's given standard specifications, the laboratory assistant develops the recipe using the spectrophotometer; writes down the details of the recipe using pen and paper and transfers the document to the laboratory supervisor who develops the worksheet accordingly. This worksheet contains information – sample details and required chemical details. The researcher suggested that the worksheet could be developed using the MS Excel format given in Fig. 3 which would take less time to prepare the worksheet and improve the writing process efficiency. It is practically found that -

Traditional Worksheet preparation time with calculation = 6 min per sheet
Proposed Excel-oriented worksheet preparation time = 2 min per sheet
The average number of worksheets prepared per day = 50
Hence, total time saved per day = 200 min

Chemical Lab Dept.

Worksheet

RECIPE NO .	YARN/FAB. :	L : R	1	6
CUSTOMER :	COUNT :	SAMPLEWT :	10	
SHADE :	QUALITY :	GSM :	175	

Dyes / Axiliaries	% / g / l			dE	TIRAL SAMPLE	Water
reddish	0.011	0.22	0.5			
reddish	0.01	0.1	1	-1-		
yellow	0.021	0.42	0.5	Date		
					25/9/19	53.26
				Dosing by		
Sub Total	0.74					
Salt	65	3.9				
Green Buff/ Soda Ash(20%)	7	2.1				
Caustic Soda (38 Be)						
Total		6.74				

Fig. 3 Proposed MS Excel Worksheet *Source: Author's creation*

4.6 Production Planning

Sometimes urgency-based sample development was done in the chemical laboratory. At that moment, it was observed that only two or three beakers were used in that batch though the machine capacity was 11-19 beakers for a single batch in a dyeing machine. When these kinds of urgency-based sample development were done, the machine utilization was as low as producing even one shade only. Again, other than some documents of RFT, no other KPIs at the department/section and individual level were found maintained.

4.7 Methodology

According to the information of the laboratory personnel, the standard rule was to store hard copies of recipes from the last three years, but it was found that recipes as old as five years still existed in the storage rack. Multiple copies of the same recipe along with some other unnecessary documents were also occupying the space. As a result, searching and finding a specific document was quite difficult and time-consuming. To sort, shine, organize, standardize, and sustain, the author suggested the common 5S methodology, and the lab responsible accepted the methodology and discussed it with all his subordinates who are maintaining organized storing of necessary items labeled properly.

5 DISCUSSION

Dyeing machines in chemical labs in textile industries in Bangladesh are being utilized less than 50%. With a proper production plan, consistent workflow, NVA activities elimination, and line balancing; these labs can perform quite efficiently. The interesting part of this research is that maintaining proper Room Temperature can be a huge saving of productive time. Also, the facility layout has the scope for improvement to reduce traveled distance during work and space to add more resources to increase capacity. To manage capacity efficiently, the chemical lab should track and prioritize samples requirement, and plan the analyst's work to manage high work in process (WIP) using a laboratory information management system (LIMS). Also, by using software like Recipe Manager and ERP system lab managers can control information and keep enough records of both trial and final approved sample recipes.

Lab managers need to keep a record – of how many additions are required to produce non-RFT samples so that they can analyze and plan the work effectively. Again, sometimes the number of incoming orders for sample production becomes inherently volatile with significant peaks and dips which causes low productivity during dips and/or long lead time during peaks (Lean laboratory, 2019). To tackle this unstable workload, Kanban (leveling workload) can be used. But when many urgent samples with long lead times are ordered, lab management should plan the production wisely, and prepare the batches with a proper combination of urgent and regular samples.

Textile engineers need to be trained on basic IE and lean concepts – Levelling workload with Kanban, 5S, Capacity, Lead time calculation, etc. Then they can simply look at the current process from IE and lean angle from time to time, describe the problem, and then present and evaluate the solutions continuously. It is easily caught in an industrial engineer's eye that if distances among machines are reduced, operators must move less, and productivity is increased. Also, at a natural room temperature, cooling machines in the lab work most efficiently. Again, the implementation of 5S always helps to decrease not only the usage of material and wear-off of tools and equipment but also the stress of employees. Also, credible measurements of improved usage of space and improved happiness of employees could be obtained after reaching the 5S auditing level (Pentti, 2014).

Overall, this case study has produced strong and verifiable data from direct observations presented in Appendix A, B, and C. There were no assumptions when concluding from the data and facts which has added validity to the outcome of this study over time. The facts presented here can be looked at continuously for further improvement. The easy approach used in this research provides everyone with analytical power to increase IE and lean knowledge. The limitation of this research is that it is done in a single company. More studies in a couple of labs in different textile industries producing different products could help to generalize the results.

6 CONCLUSIONS

Although chemical lab management is mainly focused on the development of samples and getting approval from buyers, contrary to common belief, lab managers should have some concern about productivity. The pace for sample production is usually much slower than the bulk production, but still, they should have expected a sample production rate per day, and managers should follow up on productivity accordingly. Also, 5S is found obvious to maintain cleanliness, discipline, and safety in the lab room as per two years of close observation and comments from lab workers, staff, and visitors. A future recommendation is to estimate any tangible results achievable from 5S. Further research can also be carried out with data captured in this study for value stream mapping to enlighten lab managers to visualize further opportunities to reduce waste (Yang et al., 2015) in the sample production process in all chemical labs in any textile industry in Bangladesh.

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APPENDIX A

Number of the batch: 1 Number of beakers: 14 Fabric type: 100% Cotton

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Time Duration (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks
P-1	Prepare the Recipe			I	255				Sr./ Executive	
1.1	Receive the mail from merchandising department	Computer		I						
1.2	Check the mail and print out the TCX/TPX value	Computer		1.1	94					
1.3	Go to Spectrophotometer with the printed copy	By Hand		1.2	27	840				
1.4	Enter the TPX/TCX value and select dyes for the recipe	Spectro-meter		1.3	16					
1.5	Observe the suggested color combination considering cost and select the best one	Spectro-meter		1.4	102					
1.6	Save the selected data as standard and print out the recipe	Spectro-meter		1.5	16					
P-2	Prepare Dye stock solution		102	I	120				Lab Assistant	3 Persons do the tasks together
2.1	Take the funnel from the table	By Hand			10					
2.2	Put the dyes on the weight machine	Weight Machine		2.1	30	360				
2.3	Dyes poured into the funnel	By Hand	Varies	2.2	25					
2.4	Add water into the funnel according to the requirements	By Hand	Varies	2.3	30	360				
2.5	Mixing the dyes and water	By Hand		2.4	25					
P-3	Prepare the worksheet according to the recipe	By Hand		P-1	300				Sr. Lab Assistant	This time has given for 5 recipes in 1 worksheet
P-4	Shaking Conical flux for mixing solution properly	By Hand	Varies	P-2	135				Lab boy	Total time is divided by 3 persons as they work at the same time
P-5	Prepare the dyes solution according to the recipe			P-1	1480				Jr. Lab Assistant	

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Time Duration (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks
5.1	Pour the dyes into the beaker	Electronic Digital Pipette	Varies		960					
5.2	Add leveling agents	Electronic Digital Pipette			120					
5.3	Add water according to the requirements	By Hand	Varies		130					
5.4	Weighing Salt (NaCl, Glubar) on the weight machine and poured into the beaker	Weight Machine	Varies		270	60				
P-6	Prepare the fabric or yarn for the dyeing operation			I	1240			1268	Lab boy	
6.1	Cut the fabric/yarn from the tube	By Hand	Varies		308					
6.2	Weighing the fabric/yarn on the weight machine	Weight Machine	Varies	5.1	592	240				
6.3	Wet the fabric/yarn into the mug and squeeze	By Hand		5.2	50	300				
6.4	Dip the fabric/yarn into the beaker	By Hand		5.3	290					
P-7	Fix the cap of the beaker	By Hand		P-4 & P-5	103			425	Lab boy	
P-8	Dye process			P-6	6716				Lab Assistant	
8.1	Transfer the beaker from the basin to the machine area	By Hand			11	900				
8.2	Set the beaker into the machine	by Hand		7.1	51					
8.3	Close the door and the program set up	By Hand		7.2	54					
8.4	Start the program	Dyeing Machine		7.3	6600		At half-time add Soda Ash, Caustic Soda, and Green buff			
P-9	Dispose of the beaker from the machine	By Hand		P-7	70			660	Lab boy	
P-10	Cold & Hot Wash with Neutralization				470				Lab boy	
10.1	Take the beaker on the basin	By Hand			10	900				

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Time Duration (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks
10.2	Release the cap of the beaker	By Hand			80					
10.3	Put off the fabric/yarn from the beaker	By Hand			67					
10.4	Cold wash	By Hand			66					
10.5	Hot wash	By Hand			53					
10.6	Pour fabric/yarn into the acetic acid solution (Neutralization)	By Hand			194					
P-11	Soaping procedure				2041				Lab boy	
11.1	Soaping with chemicals	Soaping Machine			886	180				
11.2	Cold wash	By Hand	2		55	180				
11.3	Hot wash	By Hand	2		51					
11.4	Soaping with detergent	Soaping Machine	2		919	180				
11.5	Hot wash	By Hand	3		62	180				
11.6	Cold wash	By Hand	3		68					
P-12	Squeeze the fabric/yarn	Squeezing Machine			58	240			Lab boy	
P-13	Drying				1322			188	Lab boy	
13.1	Fold the fabric/Yarn & put it into the machine	By Hand			110	420				
13.2	Dry the squeezed fabric	Dry Machine			1212	480				
P-14	Attach the fabric/yarn to the paper	By Hand			660	60			Executive/ Lab Assistant	
P-15	Conditioning	Conditioning Machine			602	840			Lab Boy	
P-16	Sample Assessment				366				Manager / Sr. / Executive	Time considers per sample
16.1	Attach fabric/yarn on paper to check into the dark room	By Hand			244	840				
16.2	Check the sample and make comments according to the requirements	By Hand			122	1260				
P-17	If the sample is approved, prepare the production card	Computer			185	1260			Sr. / Executive	

APPENDIX B

Number of the batch: 2
Number of beakers: 4
Fabric type: 50% Cotton & 50% Polyester

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Duration Time (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks
P-1	Prepare the Recipe			I	255				Sr./ Executive	
1.1	Receive the mail from merchandising department	Computer		I						
1.2	Check the mail and print out the TCX/TPX value	Computer		1.1	94					
1.3	Go to Spectrophotometer with the printed copy	By Hand		1.2	27	840				
1.4	Enter the TPX/TCX value and select dyes for the recipe	Spectrometer		1.3	16					
1.5	Observe the suggested color combination considering cost and select the best one	Spectrometer		1.4	102					
1.6	Save the selected data as standard and print out the recipe	Spectrometer		1.5	16					
P-2	Prepare leveling agent solution		102	I	221				Lab Assistant	3 Persons do the tasks together
2.1	Take the funnel from the table	By Hand			12					
2.2	Put the dyes on the weight machine	Weight Machine		2.1	58	360				
2.3	Dyes poured into the funnel	By Hand	Varies	2.2	34					
2.4	Add water into the funnel according to the requirements	By Hand	Varies	2.3	85	360				
2.5	Mixing the leveling agent and water	By Hand		2.4	32					
P-3	Prepare the worksheet according to the recipe	By Hand		P-1	306				Sr. Lab Assistant	This time has given for 5 recipes in 1 worksheet
P-4	Shaking Conical flux for mixing solution properly	By Hand	Varies	P-2	142				Lab boy	Total time is divided by 3 persons as they work at the same time
P-5	Prepare the dyes solution according to the recipe			P-1	1227				Jr. Lab Assistant	

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Time Duration (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks
5.1	Pour the dyes solution into the beaker	Electronic Digital Pipette	Varies		1053					
5.2	Add leveling agents	Electronic Digital Pipette			130					
5.3	Add water according to the requirements	By Hand	Varies		44					
5.4	Weighing Salt (NaCl, Glubar) on the weight machine and poured into the beaker	Weight Machine	Varies		0	60				Salts are not added
P-6	Prepare the fabric or yarn for the dyeing operation			I	296				Lab boy	
6.1	Cut the fabric/yarn from the tube	By Hand	Varies		88					
6.2	Weighing the fabric/yarn on the weight machine	Weight Machine	Varies	5.1	184	240				
6.3	Wet the fabric/yarn into the mug and squeeze	By Hand		5.2	0	300				wet & Squeeze are not needed
6.4	Dipping the fabric/yarn into the beaker	By Hand		5.3	24					
P-7	Fix the cap of the beaker	By Hand		P-4 & P-5	58				Lab boy	
P-8	Dyeing process			P-6	8385				Lab Assistant	
8.1	Transfer the beaker from the basin to the machine area	By Hand			18	1020				
8.2	Set the beaker into the machine	by Hand		7.1	38					
8.3	Close the door and the program set up	By Hand		7.2	49					
8.4	Start the program	Dyeing Machine		7.3	8280		At half-time add Soda Ash, Caustic Soda, and Green buff	543		135 Degree Centigrade Temperature
P-9	Dispose of the beaker from the machine	By Hand		P-8	55				Lab boy	
P-10	Cold Wash			P-9	104				Lab boy	
10.1	Take the beaker on the basin	By Hand			39	1020				
10.2	Releasing the cap of the beaker	By Hand			22					

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Time Duration (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks
10.3	Put off the fabric/yarn from the beaker	By Hand			20					
10.4	Cold wash	By Hand			23					
P-11	Reduction Clean Process		2	P-10	3059					Required 2 times but for urgency, RC is doing 1 time
11.1	Add caustic soda, hydrosol	By Hand			246					
11.2	Fix the cap of the beaker	By Hand			18				Lab boy	
11.3	Transfer the beaker from the basin to the machine area	By Hand			15	180				
11.4	Set the beaker into the machine	By Hand	2		32	180				
11.5	Close the door and the program set up	By Hand	2		48					
11.6	Start the program	Dyeing Machine	1		2700	180				80 Degree Temperature
P-12	Dispose of the beaker from the machine	By Hand	3	P-11	53	180				
P-13	Cold & Hot wash			P-12	230					Required 2 times but for urgency cold & hot wash are done 1 time
13.1	Take the beaker on the basin	By Hand	3		51					
13.2	Releasing the cap of the beaker	By Hand			23					
13.3	Put off the fabric/yarn from the beaker	By Hand			22					
13.4	Cold wash	By Hand			65					
13.5	Hot Wash	By Hand			69					
P-14	Neutralization Process			P-13	84					
14.1	Adding water, Acetic acid	By Hand			84					
P-15	Squeeze the fabric/yarn	Squeezing Machine		P-14	48	240			Lab boy	
P-16	Drying			P-15	1448				Lab boy	
16.1	Fold the fabric/Yarn & put it into the machine	By Hand			36	480				
16.2	Dry the squeezed fabric	Dry Machine			1412	480				
P-17	Attach the fabric/yarn to the paper	By Hand		P-16	182	60			Executive / Lab Assistant	

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Time Duration (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks
P-18	Conditioning	Conditioning Machine		P-17	183	840			Lab Boy	Required conditioning is 10 min but urgency purpose conditioning is doing 3 min
P-19	Sample Assessment			P-18	365				Manager / Sr. / Executive	Time considered per sample
19.1	Attaching fabric/yarn on paper to check into the dark room	By Hand			242	840				
19.2	Check the sample and make comments according to the requirements	By Hand			123	1260				
P-20	If the sample is approved, prepare the production card	Computer		P-19	186	1260			Sr. / Executive	

APPENDIX C

Number of the batch: 3
Number of beakers: 19
Yarn type: 100% Polyester

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Time Duration (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks
P-1	Prepare the Recipe			I	270				Sr. / Executive	
1.1	Receive the mail from merchandising department	Computer		I						
1.2	Check the mail and print out the TCX/TPX value	Computer		1.1	97					
1.3	Go to Spectrophotometer with the printed copy	By Hand		1.2	29	840				
1.4	Enter the TPX/TCX value and select dyes for the recipe	Spectrometer		1.3	18					
1.5	Observe the suggested color combination considering cost and select the best one	Spectrometer		1.4	107					
1.6	Save the selected data as standard and print out the recipe	Spectrometer		1.5	19					
P-2	Prepare Stock solution		102	I	124				Lab Assistant	3 Persons do the tasks together
2.1	Take the funnel from the table	By Hand			13					
2.2	Put the dyes on the weight machine	Weight Machine		2.1	33	360				
2.3	Dyes poured into the funnel	By Hand	Varies	2.2	24					
2.4	Add water into the funnel according to the requirements	By Hand	Varies	2.3	29	360				
2.5	Mixing the leveling agent and water	By Hand		2.4	25					
P-3	Prepare the worksheet according to the recipe	By Hand		P-1	308				Sr. Lab Assistant	This time has given for 5 recipes in 1 worksheet
P-4	Shaking Conical flux for mixing solution properly	By Hand	Varies	P-2	145				Lab boy	Total time is divided by 3 persons as they work at the same time
P-5	Prepare the dyes solution according to the recipe			P-1	2035				Jr. Lab Assistant	

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Time Duration (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks
5.1	Pour the dyes solution into the beaker	Electronic Digital Pipette	Varies		1623			461		Calculation of dyes, water pouring, Talking to each other
5.2	Add leveling agents	Electronic Digital Pipette			260			15		Worksheet handling
5.3	Add water according to the requirements	By Hand	Varies		152			82		Hovering around
5.4	Weighing Salt (NaCl, Glubar) on the weight machine and poured into the beaker	Weight Machine	Varies		0	60				Salts are not added
P-6	Prepare the fabric or yarn for the dyeing operation			I	1788				Lab boy	
6.1	Cut the fabric/yarn from the tube	By Hand	Varies		660					
6.2	Weighing the fabric/yarn on the weight machine	Weight Machine	Varies	5.1	437	240				
6.3	Yarn knotting	By Hand			579			1659		Waiting for another person
6.4	Dipping the fabric/yarn into the beaker	By Hand		5.3	112					
P-7	Fixing the cap of the beaker	By Hand		P-4 & P-5	197				Lab boy	
P-8	Dyeing process			P-7	9452				Lab Assistant	
8.1	Transfer the beaker from the basin to the machine area	By Hand			17	1020				
8.2	Set the beaker into the machine	by Hand		7.1	65					
8.3	Close the door and the program set up	By Hand		7.2	21					
8.4	Start the program	Dyeing Machine		7.3	9349		At half-time add Soda Ash, Caustic Soda, and Green buff			145 Degree Centigrade Temperature
P-9	Dispose of the beaker from the machine	By Hand		P-8	48				Lab boy	
P-10	Cold Wash			P-9	101				Lab boy	
10.1	Take the beaker on the basin	By Hand			35	1020				
10.2	Releasing the cap of the beaker	by Hand			25					

Sl. No.	Activity	Activity Type	Frequency	Independent (I) / Followed by	Time Duration (Sec)	Distance Traveled (cm)	Parallel Activity	Waiting Time	Responsible Person	Remarks
10.3	Put off the fabric/yarn from the beaker	by Hand			23					
10.4	Cold wash	by Hand			18					
P-11	Reduction Clean Process		2	P-10	3962					Required 2 times but for urgency, RC is doing 1 time
11.1	Add caustic soda, and hydrose	by Hand			241					
11.2	Fix the cap of the beaker	by Hand			19				Lab boy	
11.3	Transfer the beaker from the basin to the machine area	by Hand			23	180				
11.4	Set the beaker into the machine	By Hand	2		61	180				
11.5	Close the door and the program set up	By Hand	2		43					
11.6	Start the program	Dyeing Machine	1		3575	180				80 Degree Centigrade Temperature
P-12	Dispose of the beaker from the machine	By Hand	3	P-11	57	180				
P-13	Neutralization Process			P-12	206					
13.1	Beaker takes on the basin area				25					
13.2	Yarn put off				15					
13.3	Hot wash	By Hand			20					
13.4	Cold Wash	By Hand			21					
13.5	Adding acetic acid	By Hand			125	240			Lab boy	
P-14	Yarn Squeezing			P-13	122					
P-15	Drying			P-14	1014				Lab boy	
15.1	Fold the fabric/Yarn & put it into the machine	By Hand			125	480				
15.2	Dry the squeezed fabric	Dry Machine			889	480				
P-16	Attach the fabric/yarn to the paper	By Hand		P-15	132	60			Executive / Lab Assistant	
P-17	Sample Assessment			P-16	365				Manager / Sr. / Executive	Time considers per sample
17.1	Attaching fabric/yarn on paper to check into the dark room	By Hand			242	840				
17.2	Check the sample and make comments according to the requirements	By Hand			123	1260				
P-18	If the sample is approved, prepare the production card	Computer		P-17	186	1260			Sr. / Executive	

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