

Sustainability in Textile Manufacturing Processes by Waste Reduction: A Case Study from Bangladesh

Submitted By:

Md Abdullah Al Mamun

Master in Supply Chain Management

Supervised By:

Dr. Buics Laszlo

Assistant Professor, Department of Marketing and Management

Kautz Gyula Faculty of Economics

Abstract: The purpose of this article is to show the importance of waste reduction in manufacturing processes to achieve a higher level of sustainability. Sustainability is an important issue with many aspects, including social, environmental, and economic factors. As the level of automation is increasing among industries, the increasing amount of waste has become one of the main barriers to have a sustainable environment. That's why the sustainable manufacturing concept came to bring economic benefits while focusing on minimizing negative environmental impacts and wastes leading to energy and natural resources conservation. Moreover, this concept as a whole can induce a positive influence on the economy of a country.

The economy of Bangladesh is greatly dependent on export earnings, in which the readymade garment manufacturing industry marks more than 80%. But, this sector is filled with many problems and excessive wastage is one of the biggest. This is bringing an enormous amount of negative impact on the environment as well as the economy of the country.

Hence, this article uses the production processes of a textile garment factory located in Bangladesh as a case study to examine how waste reduction can be achieved. First, the major steps of the production process are mapped and visualized to identify improvement opportunities by using the Business Process Modeling Methodology. Secondly, after the production process is improved an experimental test is conducted to see how much waste reduction can be achieved by the proposed solution.

The authors found that the in-sewing wastage in the factory was too much and used compressed air as a suggested solution to minimize this problem. The final result of the test showed that the in-sewing fabric wastage percentage had been reduced almost by 75%. There is a higher possibility that if this solution is implemented properly it will help to minimize the wastage to a satisfactory level and will help the owners to increase the overall profit as well.

Keywords: Sustainability, Waste Reduction, Textile Manufacturing, Production Process, Business Process Modeling

1. Introduction

Manufacturers around the world are struggling over the years with the gradual increase in compliance, energy, and material costs. Since the beginning of modernization and as soon as automation started to show up, the environment surrounding us started to lose its balance (Ching et al., 2022). To restore what is lost and not destroy anymore, the concept of sustainability showed up which involves many important aspects such as environmental, social, economic, and personal (Simangan et al., 2022). United Nations' 17 Sustainable Development Goals (SDGs) are fixed now to end poverty, protect the planet and ensure prosperity and to be achieved by the end of 2030 (Bhatnagar et al., 2022).

Nowadays, almost everything that we use in our daily life is automatically manufactured. The fast reduction of natural resources due to increased manufacturing processes and a higher percentage of ecological imbalance has attracted the government and respective authorities to call for sustainable development among manufacturing industries and that's how the phrase "Sustainable Manufacturing" came (Bhatnagar et al., 2022; Hariyani et al., 2022). The phrase evolved based on focusing on creating goods by using processes and systems that are non-polluting, able to conserve energy and natural resources in economically viable, safe, and healthy ways for employees, consumers, and all related stakeholders considering the short and long-term goals. Hence, to achieve sustainable development for manufacturing industries, governments, organizations, policy-makers, and stakeholders are driving the value chain partners to transform the traditional economy into a green economy as the transformation greatly depends on green innovation (Hariyani et al., 2022; Sharma et al., 2022).

Bangladesh has been a great manufacturing location for a long time. The major industries are textile and clothing, leather, frozen food, pharmaceuticals, petroleum, and chemicals. But, the readymade garments manufacturing industry is the biggest among all of them and contributes more than 80% in foreign earnings (Nazrul & Rahman, 2021). As the demand for fast fashion is increasing rapidly around the world, clothing manufacturing and related transportation is generating a large amount of greenhouse gas emissions (Centobelli et al., 2022). According to some statistics, Bangladesh is the second-largest manufacturer of readymade clothing exporting clothing for leading and world-famous fast fashion brands such as H&M, ZARA, C&A, and so on.

With environmental issues rising up around the world and sustainability concepts being discussed frequently, fashion brands are becoming aware. Hence, the manufacturers like Bangladesh are having requests from their buyers to implement an environment-friendly system or transform the conventional clothing manufacturing process into a sustainable one (Nazrul & Rahman, 2021; Centobelli et al., 2022). The requests of reducing the amount of textile waste from the brands are coming in different fronts such as fiber, yarn, and fabric production, wet processing, and assembling of the clothing. These involve both liquid and dry wastes (Akter et al., 2022). These sudden change requests in the regular manufacturing processes are putting the manufacturers in a tough situation. In the case of manufacturers in Bangladesh, they are trying their best to follow the buyer's environmental compliance requirements in fiber/yarn/fabric production wastes or dyeing process wastes by implementing necessary measures. But, when it is coming to readymade garments manufacturing, the management is having trouble following the standard or modifying the process as it also affects the overall productivity like the rest of the world (Centobelli et al., 2022).

As a result, Manufacturers who are not being able to comply with the customer's environmental requirements are continuously losing orders. Fashion brands are turning their back on readymade garment suppliers which started to affect the developing economy of Bangladesh on a small scale ready (Ahmed et al., 2022). So, to maintain these incoming sustainability-related requests in order to keep rotating the economy of Bangladesh by manufacturing readymade clothing for world-leading brands, the manufacturers perceived that the traditional garment manufacturing process modification is urgent and they have started to take initiatives on their own to maintain the same (Centobelli et al., 2022; Maalouf & Hoque, 2022). That's how sustainability is coming into the readymade garments manufacturing industries of Bangladesh but at a slower pace.

2. Literature Review

The development of a green economy has become a popular concept around the world in recent times. The constant buildup of the green economy needs the help of green innovation to ensure organized improvement of the surrounding environment and climate. With automation and manufacturing taking over the advancement of the current world, the environmental balance as well as the green economy concept is being challenged (Sharma et al., 2022). That's when sustainability is coming to intervene in order to solve the challenges. It was introduced as a balance

between the environment, equity, and economy. The sustainability practice supports ecological, human, and economic health, and vitality. It helps to presume that resources are finite, and should be used conservatively and wisely with a view to long-term priorities and consequences of the ways in which the resources are used (Kumar et al., 2020; Hasan et al., 2020). That's how sustainable development fulfills the needs of the present without compromising the ability of future generations. But, sustainable development is not so easy to gain. It is a social challenge that includes international and national law, proper urban and transportation planning, local and individual lifestyles, and ethical consumerism. As a result, it deals with green technologies, renewable energy, sustainable fission, and fusion power in a flexible and reversible way. This universal approach and constant progress of sustainable development can lead to the final point of achieving full pledged sustainability (Hasan et al., 2020).

One important way to reach the goals of sustainable development is to make the manufacturing processes green and eco-friendly. World-class manufacturers have already taken all the required initiatives for better contributing to economic and socio-environmental development. Many industrial reports and statistics showed that sustainable manufacturing processes can unravel better profit-making opportunities and improve competitiveness (Ching et al., 2022). But, achieving sustainable manufacturing processes across all the plants of a country or implementing such processes among all industrial sectors is not so easy. But, Industry 4.0 came with the exact opportunity to have so. It is a combination of several advanced technologies which have the ability for businesses to renew and update their processes by using these latest technological solutions.

Integration of Industry 4.0 can help manufacturers to have improved decision-making abilities while organizing their resources efficiently and hence it can be identified as an enabler of an efficient and lean operation (Dixit et al., 2022). Sustainable manufacturing and lean practices have the ability to create an intelligent network system that improves productivity, quality, and customer orientation while eliminating waste. Moreover, by incorporating Industry 4.0 with lean practices strategically and after successful integration, the whole sustainable manufacturing initiatives have the potential to bring enormous benefits for the manufacturers such as an increase in competitive advantage and cost savings due to material, energy, and resource efficiency (Ching et al., 2022; Dixit et al., 2022).

One of the oldest and currently one of the biggest manufacturing industries is textile and clothing. Fast fashion companies are transforming the way of clothing consumption by customers. Instead of releasing garments based on season, the fashion brands are introducing new styles weekly or even in some cases daily at lower prices. According to Statista, the global revenue from the apparel market in 2021 was US\$1.5 trillion and by the end of 2026, it might reach the US\$2.0 trillion threshold. As a result, like other manufacturing industries, the textile and apparel industry is producing a lot of waste making it environmentally unfriendly. Moreover, the increased demand for low-priced clothing involves high volumes of synthetic or petroleum-based components being used which is leading to an increasing amount of greenhouse gasses and landfill wastes. As a result, many international organizations are pointing out the textile and garment industry as one of the leading industries with respect to violation of sustainability rules (Wren, 2022; Elmogahzy, 2020).

In general, clothing and textile wastes can be classified into two types in general which are pre-consumer and post-consumer waste. Pre-consumer wastes are- process waste, damaged/unsold clothing waste, cut-sew waste, end-roll waste, sampling yardage waste, and so on and post-consumer wastes start generating once the product is sold (Jamshaid et al., 2021; Enes & Kipoz, 2021). The process wastes include both liquid and dry wastes. The liquid wastes are usually generated from dyeing and chemical treatment processes which involve a lot of chemicals. With concerns raising around the world regarding the environment and waste management, fashion brands are urging manufacturers to manage textile waste properly. Hence, the manufacturers are trying to maintain the same as well (Akter et al., 2022; Maalouf & Hoque, 2022).

There have been experiments on reusing fashion waste collected from consumers into fiber blends to reuse as a filling material in children's flame-retardant mattresses. The fiber blends were analyzed, treated with eco-friendly flame retardant finishes, and went through several other follow-up treatments to be usable (Nayak et al., 2021). The liquid wastes that come from the chemical treatment and dyeing processes are also treated in several ways before being released again into the environment as the whole textile dyeing process depends solely on groundwater. This treatment is being done in an effluent treatment plant to get rid of chemicals used in dyeing, printing, finishing, and other processes. As a result, this water becomes reusable and acts as a major pillar for groundwater conservation (Haque et al., 2021). Moreover, there is a lot of research ongoing which is focusing on the generation of energy from textile bio-waste. These include bio-alcohol,

and bio-diesel from textile solid waste, bio-gas, bio-electricity, and bio-hydrogen from textile waste via several chemical and engineering processes (Khandaker et al., 2021).

Bangladesh, one of the global key hubs of clothing manufacturing started to excel in the industrial sector with its first export shipment in 1978. Hence, the quick and continuous growth of the economy of Bangladesh is mainly driven by the readymade garments sector (Majumder & Ferdous, 2020). In the beginning, it was seen as a very small and non-traditional export sector but who knew that this sector will shape and rewrite the economy in a better way and will lead the economy of the country (Rahman et al., 2017). According to the latest statistics published by Bangladesh Garment Manufacturers and Exporters Association (BGMEA), in the fiscal year of 2020-21 when the covid-19 pandemic hit the world hard, the percentage of RMGs-to-total export in the case of Bangladesh was almost 82% and the year before it was almost 84% (Majumder & Ferdous, 2020; Rahman et al., 2017). There were some supporting factors behind this kind of huge success.

One such important factor was the quota system which gave Bangladesh an upper hand back then over Hong Kong and Korea as Bangladesh was marked as LDC and they were ranked as non-LDC. The quota policy continued until 2004 and by then Bangladesh got all the required fame in the world market (Rahman & Chowdhury, 2020). Besides, the vast population of the country also acted as another important factor as it was possible to employ the uneducated huge labor force into garment manufacturing really fast with less time-consuming training (Rahman et al., 2017). In addition to these, cheap labor, favorable trade policies, duty-free import laws, and loan facilities administered the necessary booster to take the sector up to its rightful place which we are seeing now (Majumder & Ferdous, 2020; Rahman & Chowdhury, 2020). Even though the country is advancing in its economy thanks to the clothing sector, a matter of grave concern is the waste being generated through this sector and it is becoming one of the biggest threats to the environment of Bangladesh (Jamshaid et al., 2021).

In the literature review above, there were a lot of talks about how to turn the waste into value-added materials and hence minimize the waste percentage or how to turn the waste into eco-friendly waste before releasing it into the environment which of course requires some after-treatment and incurs costs. But, none of the research was talking about reengineering the whole process or redesigning the existing approach to manufacturing. To cope with the buyer's requirements, RMG factories in Bangladesh are trying to adopt cleaner and improved technology

which is being used worldwide. This is helping to maintain the sustainability standards set by the fashion brands but it is also backfiring the manufacturers in the sense that additional after-manufacturing processes involve a lot of set-up costs, infrastructure costs, and process costs (Hasan et al., 2020; Elmogahzy, 2020). Moreover, most of the ongoing research is being conducted within the area of wet textile waste. This involves mainly after treatment of the discharged liquids from several textile processes such as dyeing, production, finishing, printing, and so on.

But, Bangladesh is mainly manufacturing readymade garments which especially generates dry textile waste. But, all these wastes fall within the area of pre-consumer waste. As demand for fast fashion is constantly rising worldwide, hence the percentage of clothing production is increasing continuously, and as a result, pre-consumer wastage is amplifying as well and this has become the main waste within the whole textile sector and its stakeholders (Akter et al., 2022; Haque et al., 2021; Moorhouse, 2020). But, because of receiving less attention from researchers around the world on how to reduce waste percentage, the clothing manufacturing sector (cutting, sewing, finishing sections) is becoming the major wastage generation point within the overall textile industry (Rahman & Haque, 2016). To deal with this, sustainable clothing manufacturing practices are gaining more attention among manufacturers now-a-days.

These include re-engineered manufacturing processes, a fair wage structure, a better working environment, and nature-friendly raw materials (Moorhouse, 2020). One of the suitable and cost-friendly ways to bring sustainability into the clothing manufacturing sector is to redesign the manufacturing process however possible. This can be done by studying the whole manufacturing process of a product line while trying to identify the root cause behind the waste generation and the inclusion of some assistive technology to bring the required innovation and redesign. It can come from Industry 4.0 or can be something very general but unexplored (Dixit et al., 2022; Elmogahzy, 2020).

In some latest publications related to clothing manufacturing engineering, the authors showed that even slightly re-engineered garment manufacturing processes can bring about enormous benefits. In 2018, Mafzal Ahmed, Md Salimuzzaman, Sheikh Sha Alam, Golam Kibria, Champa Saha, and Shadman Ahmed Khan published a paper named “Improvement of Productivity in Garment Assembly Section by Using Work Aids” where they used different types of sewing work aids in a manufacturing line and did a time study to show the overall improvement of productivity of that

sewing line (Ahmed et al., 2018). In 2017, A.F.M Fahad Halim, and Mohammad Rashel Hawlader posted a paper titled “Significance of the Use of Sewing Work Aids in Garments Production”. They did an SMV analysis here and showed that with the help of work aids, the final output is much higher compared to what it was before. Also, they carried out a cost analysis and pointed out that the production cost has been reduced as well (Halim et al., 2017). In 2020, Solomon Tilahun worked on a topic called “Optimization of Production Process in Sewing Work for Ethiopia Cultural Clothe Apparel Production” where he used several folders as work aids to improve the quality of the clothes and productivity of the sewing line (Tilahun, 2020).

On a sewing floor of a clothing manufacturing plant, the major wastage yields from overlock operation which is done by an overlock sewing machine. The machine itself has a fabric trimmer associated with it that cuts the edge of the fabric professionally while continuing the stitching process to produce a neat seam (Ramkalaon & Sayem, 2020; Jaouachi et al., 2019). Usually, textile professionals say that fabric is the most valuable raw material at the industry level. According to the cost analysis of a garment, the cost of fabric carries almost half of the garment’s value. So, if we can minimize the cut and sew as well as in-sewing fabric wastage not only it will affect the profit of the manufacturing plant but also the concept of sustainability as minimizing waste is one of its prime focuses (Enes & Kipoz, 2021; Moorhouse, 2020).

With the inclusion of appropriate technology, such waste can be minimized to an optimum level and the required sustainability level can be achieved at the same time. Compressed air can be one similar technology that has the ability to reduce this sort of cut-and-sew waste from the sewing floor. It is one of the most versatile carriers of energy and is being widely used in many industrial processes for a long time. Moreover, at least one compressed air supply line can be easily found in any clothing manufacturing plant which is mainly used for cleaning purposes but can also be used as a feasible work aid to support an operator’s work in terms of quality, quantity, and wastage reduction with the inclusion of appropriate instrument and properly redesigned garment manufacturing process (Sarwar et al., 2021; Eras et al., 2020; Ansari et al., 2019).

For example, in the case of knit fabrics, there is always a tendency for the fabric ends to curl. During stitching attempts of such fabrics in the overlock machine, it results in excess fabric edge trimming by the trimmer on the machine to remove curliness and smoothen the operation. Compressed air can help to minimize this curliness by being blown off from above and below the

fabrics and hence the edges will flatten up and the operation will be smooth, sewing wastage will be less (Jana, 2015). That's how by minimizing waste, sustainability can be brought into the textile and garment manufacturing industry and simple process optimization or re-engineering, or inclusion of a simple technology within the existing manufacturing process can help to achieve the ultimate goals of sustainability.

3. Research Questions

Why excessive sewing wastage is being generated in the selected clothing manufacturing plant from Bangladesh and how the re-engineering of the usual manufacturing process can bring an optimized sustainability level within the plant by reducing waste? What can be the estimated cost of manufacturing process re-engineering and what are the potential benefits that can be achieved through this?

4. Research Methodology

The research idea came from the sense of minimizing pre-consumer (dry in-sewing) waste within the plants of Bangladesh. A clothing manufacturing plant was selected. The manufacturing process of a product line was studied and observed to find out the major waste generation point. After that, the existing manufacturing process was analyzed deeper and re-engineered according to the requirement after several trials. New data were collected to compare with the existing data and analyze further to find improvements. The process flow of the whole research has been visually represented below:

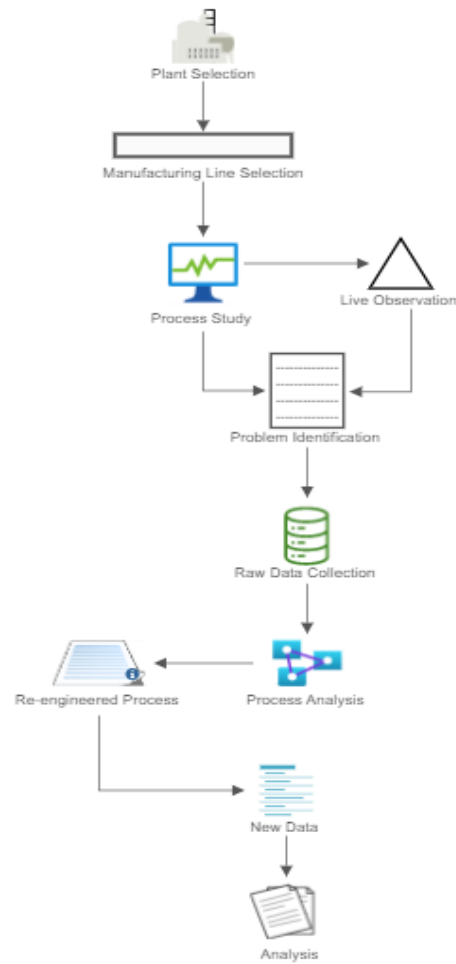


Figure 1: Visual Representation of the Research Flow

5. Product Description

The factory produces clothing out of knit fabrics. The selected product line was manufacturing kid's tops for the clothing brand "GEORGE" which is exclusive to Walmart. The purchase order was also under the name of "Walmart". Technical details of the product are as follows-

Style- Kid's Top (solid dyed)

Color- Pink

Fabric construction- Single jersey, 160 GSM

Fabric composition- 100% cotton

The photo of the selected product has been shown below in Figure 2:



Figure 2: Product Chosen for the Study

6. Existing Manufacturing Process

To identify the major waste generation point and related problems, the existing manufacturing process flow of the line was collected and studied. Besides, the whole process was observed live to see how the operators were executing their work.

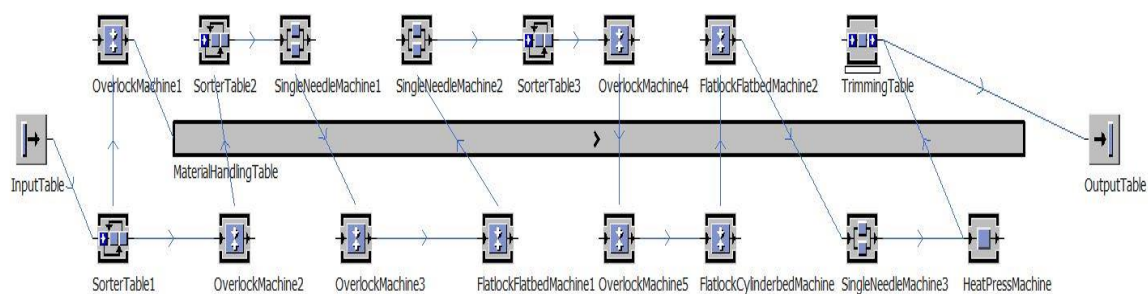


Figure 3: Manufacturing Sequence of the Selected Product

The cut pieces required to manufacture complete garments are carried out to a table called “Input Table” (shown on the leftmost side of Figure 3). Then, the cut pieces travel through a series of

sewing machines and the products start to be manufactured. Each machine and operator is responsible for doing only the specified task. Once the task is finished, the half-finished product goes to the following machine for the next task. Below in Figure 4, the machine-wise task list has been specified.

No	Machine Type	Operation Description
1	Manual	Front and back match
2	4T O/L	Joint Both Shoulder
3	4T O/L	Neck piping
4	Manual	Neck rib thread open, measure, cut
5	SND-LS	Neck rib tack
6	4T O/L	Neck rib surging
7	2T F/L-BD	Back neck binding
8	SND-LS	Back Neck top stitch
9	Manual	Sleeve match with body
10	4T O/L	Sleeve attach
11	4T O/L	Joint both side seam
12	3T F/L-CB	Sleeve hem
13	3T F/L-HM	Bottom hem
14	SND-LS	Attach care label
15	Heat Seal Press	Heatpress label attach
16	Manual	Thread trim

Figure 4: Operation Bulletin of the Selected Product

*4TO/L= 4 Thread Overlock Machine, SND-LS= Single Needle Lock Stitch Machine, 2T F/L-BD= 2 Thread Flatlock Flatbed Machine, 3T F/L-CB= 3 Thread Flatlock Cylinder bed Machine, 3T F/L-HM= 3 Thread Flatlock Hem Machine, Heat Seal Press= Heat Press Machine, Manual= Manual Task done by an operator.

7. Problem Description

During the careful review of the whole operation, it was seen that the excessive sewing wastage was coming out mainly from the overlock machine during the body side seam operation.

1. When the operator was carrying out the body side seam operation in the overlock machine, the required edge-neatening task done by the knife associated with the machine was cutting down the curly edges of both sides of the product. It is because the knit fabric has the general tendency of being curled on the sides. When the operator was being careful with the task, the wastage percentage was remaining within the approved tolerance limit. But the operators were not being accurate and patient while doing the task as they have a specific SMV for each operation and an hourly target to maintain. That's because, if they fail to keep up the pace and maintain the specified SMV, the task becomes a bottleneck operation impacting the final output and hourly target of the line. As a result, to get rid of bottlenecks and keep up the specified SMV, the operator was doing the task in the usual way, and hence a lot of unwanted sewing waste was coming out each time.



Figure 5: An Example of Generated Sewing Waste in the Overlock Machine

2. Due to this, the operator's performance and line output were being affected as well sometimes when the operator was trying to do the side seam overlock operation carefully in the machine. Hence, it was taking more time and was affecting the final output.
3. Moreover, due to the excessive waste generation from the body side seam overlock operation, the pattern maker needs to adjust the pattern each time and had to add more waste percentage in the final pattern than the approved tolerance limit and it was increasing the overall fabric consumption for each product and finally the net profit was getting less because of this.

The Ishikawa Diagram below in Figure 6 is showing the causes in detail which worked as factors behind the problems stated above.

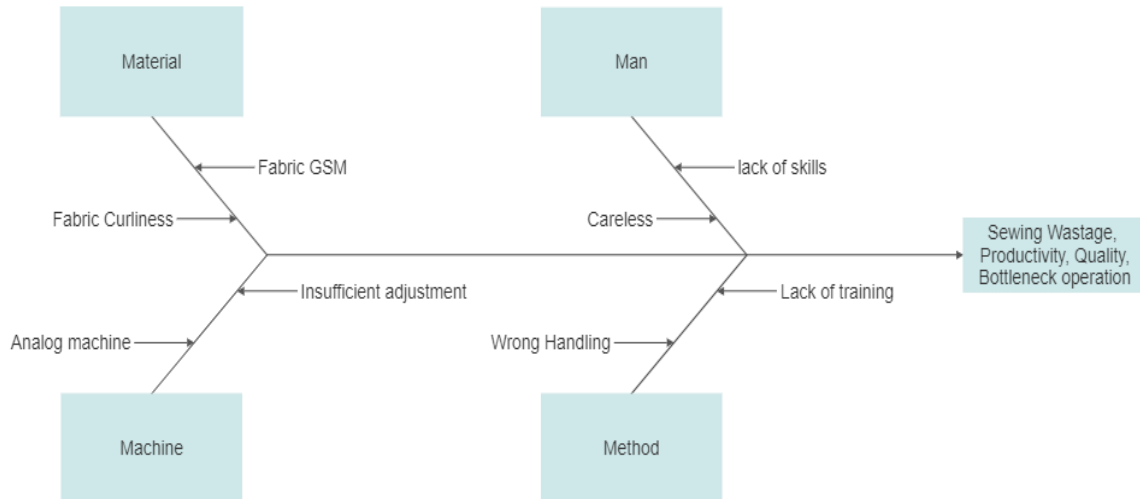


Figure 6: Ishikawa Diagram for Causes and Effects Identification

8. Re-engineering of the Existing Manufacturing Process

After studying the existing manufacturing process, and carefully reviewing the identified problems and all the available options within the plant, the idea was to implement compressed air as the assistive technology within the production line (where required) to minimize the sewing waste to an optimized level matching to the sustainability standard. This is because the curliness of the fabric was the root cause behind such wastage and compressed air has the ability to eliminate such curliness if it can be used appropriately. Also, compressed air was already being used in that plant for other purposes such as cleaning, and pressurizing of some other machines, so it will not be a problem to implement it for other industrial work purposes as no new investment or setup cost will be required.

8.1 Air Flowing Device:

The very first issue raised with using compressed air as the manufacturing assistant was technical as the application area was small and required preciseness. So, a small device was made to apply compressed air during the overlock sewing process in that small, specific area of the machine and it was built in a way so that it can be attached to the presser foot of the machine. The device was made as per design specifications confirmed by the research team and a factory technician made it accordingly. Figure 7 below shows the air-flowing device that was made to supply compressed air.



Figure 7: Air Flowing Device Made to Supply Compressed Air

Technical specifications of the device are as follows:

Material- Copper

Diameter- 0.6 cm

Total length- 7 cm

A small round-shaped hook was welded to the device in such a way so that it can be attached to the presser foot of the machine with a small screw. The bottom part of the device was smashed so that it becomes flat and air comes out in a flat manner.

8.2 Description of the Re-engineered Manufacturing Process:

1. From the central compressed air generator of the factory, the air comes into the sewing floor through the horizontal overhead pipes.

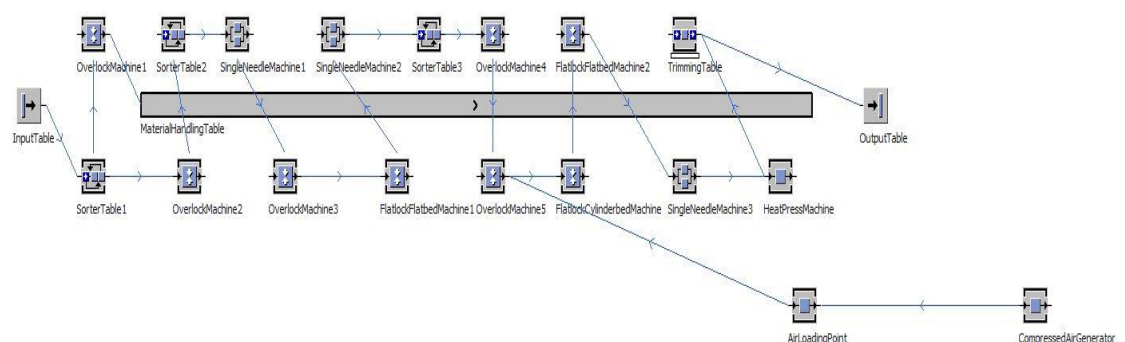


Figure 8: Re-engineered Manufacturing Process to Reduce Waste Level

2. Then via vertical steel pipes the air comes into loading points in each sewing line and each point has an on/off switch to control airflow. From the loading point, via horizontal pipes (runs 0.5m above the floor), the central compressed air can be connected to each machine into an air meter which is connected to the pedal of the machine.
3. To bring the compressed air connection from the air meter to the actual operation area of the overlock machine, an additional connection was added after discussing the feasibility and going through several trials. The other side of this extended connection was attached to the circular (top) part of the air-flowing device. The device was then attached to the presser foot of the sewing machine.
4. When the operator started sewing by pressing the pedal down with her foot, compressed air started to come out of the air-flowing device.



Figure 9: Connection of the Air Flowing Device with the Presser Foot of the Machine

5. The high-speed compressed air flow was straightening the curly edges of the garment during sewing. As a result, the fabric wastage had reduced as the machine knife was not having a lot of excessive fabric edges to cut down and the operator also did not have to put much effort as well to straighten out the fabric edges while sewing.
6. As a result, some immediate visual improvements were noticed. The waste was way less compared to before in the same machine. It also looked like the worker could finish each task faster than before.

9. Difference between Existing and Re-engineered Manufacturing Processes

The major difference between the existing and updated working process has been discussed in short in Table 1 below:

Existing Manufacturing Process	Updated Manufacturing Process
In the existing working process, when the operator was doing the body side seam operation in the overlock machine, the knife associated with the machine was cutting the edges even more than the allowance because of the tendency to curl at the edges.	In the re-engineered manufacturing process, the highly speedy compressed air was coming out of the device during the sewing operation, minimizing the curliness and hence sewing wastage came down to a minimum level.

Table 1: Comparison between Existing and Updated Manufacturing Processes

10. Data Analysis

To find out the effectiveness of the solution, 2 sets of data were collected from the identified task. The first set was collected during the existing work process and the second set of data was collected after the implementation of the suggested solution.

10.1 Collected Data from the Existing Process:

Data were collected over 5 days for an hour from two different shifts from the existing manufacturing process.

Date	Duration (hr.)	Shift	Sewing Waste (gm.)	Average waste (gm.)	Output (pc)	Average Output (pc)
26-June-2022	1	Morning	145.7	143.36	116	116.3
	1	Afternoon	139.2		121	
27-June-2022	1	Morning	148.6		115	
	1	Afternoon	144.1		118	
28-June-2022	1	Morning	140.8		122	
	1	Afternoon	138.9		119	
29-June-2022	1	Morning	146.5		110	
	1	Afternoon	148.9		117	
30-June-2022	1	Morning	138.5		116	
	1	Afternoon	142.4		109	

Table 2: Collected Data of Sewing Waste and Output from the Task in the Existing Process

10.2 Collected Data from the Reengineered Manufacturing Process:

Data were collected over 5 days for an hour from two different shifts from the re-engineered manufacturing process.

Date	Duration (hr.)	Shift	Sewing Waste (gm.)	Average waste (gm.)	Output (pc)	Average Output (pc)
24-July-2022	1	Morning	36.3	36.56	144	141.8
	1	Afternoon	36.1		139	
25-July-2022	1	Morning	35.9		141	
	1	Afternoon	38.1		140	
26-July-2022	1	Morning	37.2		145	
	1	Afternoon	35.6		137	
27-July-2022	1	Morning	36.9		137	
	1	Afternoon	35.4		142	
28-July-2022	1	Morning	37.7		145	
	1	Afternoon	36.5		144	

Table 3: Collected Data of Sewing Waste and Output from the Task in the Updated Process

10.3 Improvement Analysis:

After collecting 2 sets of data over a definite period of time, both sets of data have been compared against each other to find out the improvement. Table 4 below is showing the comparison in a simple manner to point out the improvement.

Method	Average waste (gm.)	Average Output (pc)
Existing method	143.36	116.3
Updated method	36.56	141.8
	Reduction= 106.80	Increase= 25.5

Table 4: Improvement Comparison between Existing and Updated Methods of the Task

From the data obtained through the whole study and after the detailed analysis done above, it can be said that the reduction of waste and increase in output within the identified problematic

operation and machine is huge. Almost 107 gm of process waste can be reduced per hour and 26 pieces of higher output can be gained per hour from the aforementioned overlook operation if the existing manufacturing process is modified according to the idea shown in this study. The percentage of the reduced waste can be derived from Equation 1 below:

$$\frac{x=(143.36-36.56)*100\%}{143.36} \dots\dots\dots \text{Equation (1)}$$

Here, X is the percentage of reduction in sewing waste which was found by the result of subtracting fabric waste from the existing method to the updated method divided by the existing method, and multiplied by 100. The calculation tells that 74.49% of waste can be reduced if the re-engineered manufacturing process is applied to the problematic overlook operation.

Same as above, the percentage of the increased output can be derived from Equation 2 below:

$$\frac{y=(141.8-116.3)*100\%}{141.8} \dots\dots\dots \text{Equation (2)}$$

Here, Y is the percentage of increase in output which was found by the result of subtracting output from the updated method to the existing method divided by the updated method, and multiplied by 100. The calculation tells that 17.98% of output can be increased than before if the re-engineered manufacturing process is applied to the problematic overlook operation.

11. Cost-Benefit Analysis

The cost-benefit analysis done here is based only on the selected garment manufacturing line for this study.

11.1 Costs of Re-engineered Manufacturing Process:

The complete setup, utilization, and investment cost (if any) of Compressed Air and the Air Flowing Device is shown below in Table 5. It is to note that, the actual cost might vary on a case-by-case basis. There is already a central compressed air setup in the plant. Hence, no new setup is required.

Cost Description	Required Unit (L)	Price/Unit (\$)	Total Cost
Compressed Air Cost per Overlook Machine per Hour	1.5 L	\$1	\$1.5
Working Hrs./Day= 10			

Compressed Air Cost per Overlock Machine per Day	15 L	\$1	\$15
Setup Cost			Not Required
Additional Investment Cost			Not Required
Cost of Making an Air-Flowing Device			\$1
Connection Cost			\$2

Table 5: Total Cost Related to Updated Manufacturing Process

From the above calculation, it can be seen that if the re-engineered process is applied, only \$15 will be the estimated daily cost for the specified overlock operation within the selected product line and \$3 will be a one-time setup cost of the air-flowing device.

11.2 Benefits Achieved from Re-engineered Manufacturing Process:

Two types of benefits were seen after implementing the modified manufacturing process. One was the hourly increase in output of the bottleneck operation. The estimated net hourly increase in revenue due to the updated process is shown below in Table 6.

Current Hourly Output on the Specified Body Side Seam Overlock Operation	125 pcs
Average Output from Other Tasks	145 pcs
Bottleneck Operation: Body Side Seam Overlock Operation	
Can achieve Hourly Output (according to the modified process described in this study)	140 pcs
Calculated Hourly Increase in the Final Output	15 pcs
Price Per Garment	\$3
Net Hourly Increase in Revenue	(15x3)= \$45

Table 6: Benefits Achieved via Hourly Increase in Production

To keep up the quality and to match the dimension requirement of the final garment, the pattern maker was giving an additional 0.5 cm tolerance to each of the parts of the garment. This was being done so that the final measurement of the finished garment matched the dimension chart provided by the buyer. As the knife associated with the overlock machine was cutting more than

the approved waste tolerance limit during the side seam operation, the only solution they have got was to add more tolerance to the existing pattern to keep the final body dimension accurate. This is described (in detail) below in Table 7.

Panel Dimension (Length x Width) Used by the Pattern Maker for the Mentioned Product	(44 cm x 31.5 cm)
Reduced Panel Dimension (Length x Width) Achieved from the Experimented Process	(44 cm x 31 cm)
Reduction in Dimension	0.5 cm (width wise)
Average Fabric Consumption per Garment	500 gm
Calculated Fabric Savings per Marker	15~20 gm
Fabric Price per Kg.	\$1.05
Total Number of Garments per Purchase Order	5000~8000 pieces

Table 7: Profit Gained from the Pattern Adjustment

From the above table, it can be seen that a certain amount of fabric can be saved in each marker due to the implementation of the re-engineered process shown in this study. This can reduce the total cost of fabric per garment in the cost sheet and minimize the whole material cost of a garment to some extent. Hence, the net profit percentage per purchase order can be increased.

12. Research Implications

The major drive behind this study was to bring sustainability within a clothing manufacturing plant by reducing certain process waste. As it was found that the main process waste generation point was the overlock machine doing the body side seam operation, so the research goal was to minimize waste generation percentage in that task which was done by implementing compressed air as the assistive technology. Moreover, there were many cases of rejection of finished garments because of the size issue, and in most cases, it happened because of the excessive edge cutting by the knife associated with the overlock sewing machine in the identified operation. The new data showed that the modified manufacturing process helped to minimize edge-cutting by two-thirds compared to what it was before. It is also calculated that with proper implementation of this method, there will be savings of fabric in the pattern due to the adjustment of waste tolerance which will be leading to the reduced price of a finished garment and an overall increase in profit.

But, this research has some limitations as well. The newly developed manufacturing method was applied to only one garment manufacturing line within the plant. Hence, the re-engineered process is yet to test on a wide scale. Moreover, making the air-flowing device was tough because of the material requirement and it took some time to make the device perfectly. The operator did not seem quite comfortable at the beginning working with the modified manufacturing process as compressed air was coming out at a high speed during the operation.

13. Conclusion

Sustainability is actually meeting daily needs without compromising the ability of future generations to meet their own needs. This is not only just about environmentalism but the economic and social resources should be considered as well. That's how the green economy concept is connected to sustainability and in order to continue the same, sustainability is coming into manufacturing as sustainable manufacturing that focuses on minimizing waste and reducing negative environmental impact. These goals can be obtained mainly by adopting practices that influence process design, product design, and operation principles. Hence, the sustainable manufacturing system can be defined as an idea that can integrate product and process design issues with issues of manufacturing, planning, and control to effectively assess, reduce, and manage the flow of waste.

Considering the above statements, this study was performed as the textile and garments industry is raising concerns worldwide due to the sustainability issue. Specifically, the readymade garments manufacturing industry was receiving a lot less concern regarding sustainability from researchers around the world.

The paper showed an improved way of performing the task which was found as the main waste-generating point in a selected sewing line within a factory. With compressed air, ready to blow on an experimental setup via an air blower device it was really possible to reduce the wastage percentage. The result showed that the process waste percentage had been reduced by almost 75% compared to before. However, as it was only been experimented on one sewing line, results might not be the same for others. So, it would have been better if the process could be implemented within multiple sewing lines following the success of this study and understand the result from a bigger perspective.

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