Economic and environmental advantages comparing two technological alternatives for denim weaving

Ariane Gaiola de Oliveira Sanches
Universidade Nove de Julho – UNINOVE – São Paulo - Brazil

Wagner Cezar Lucato
Universidade Nove de Julho – UNINOVE – São Paulo – Brazil
wlucato@uninove.br

Geraldo Cardoso de Oliveira Neto
Universidade Nove de Julho – UNINOVE – São Paulo - Brazil

Abstract
The objective of this work is to analyze the environmental and economic gains resulting from the utilization of a Design for the Environment (DfE) perspective, comparing two weaving technologies for denim production. The research method consisted of a case study in which the results obtained for two technologies were compared.

Key words: Design for the Environment (DfE); Environmental management; Denim weaving.

INTRODUCTION

Brazilian textile sector has significant importance in both job creation and industrial production value. In 2012, the sector accounted for 5.5% of total value produced and 15.2% of jobs in the country's manufacturing industry. The weaving sector, which is the focus of this paper, comprises 579 industries in Brazil. They employ 98 thousand workers and produce approximately 1.3 million tons/year of fabrics of which 60% are made from cotton. Equipment investment for weaving represents US$ 100 million a year (IEMI, 2013).

In the last years, the large retailers that are among the weaver's main customers have suffered increasingly pressure from public opinion on environmental issues, chemical safety and social responsibility (FGV, 2009). End user customers are gradually engaged in campaigns against the use of toxic textiles (Greenpeace, 2014). The necessity to implement tools focused on sustainability has been introduced by government (environmental laws and control policies), market competition (competitors, investors and consumers) and social and environmental responsibility (Pimenta and Gouvinhas, 2012).

Equipment are the main investment in the weaving sector, more specifically in weaving machines (looms). They consume a significant amount of electricity to convert yarns into fabrics. Some studies addressed the energy use in the textile industry (Hasanbeigi and Price, 2012;

Martínez, 2010), but they have not considered the yarn waste generated in different kinds of weaving technologies and their consequent environmental impact.

The aim of this study is to assess the economic and environmental advantages of the utilization of the Design for the Environment (DfE) considering two main technologies used to manufacture denim fabrics, identifying as a result potential environmental and economic gains. This paper presents a theoretical background on Design for the Environment and economic and environmental gains, followed by a case study based on semi-structured interviews.

THEORETICAL BACKGROUND

The theoretical background addresses the concepts associated to the Design for the Environment (DfE) and the economic and environmental gains.

Design for the Environment (DfE)

Design for the Environment (DfE) evaluates a product from its creation to the final disposal, that is, throughout its entire life cycle, focusing on minimizing its impact on the environment. It involves the most appropriate selection and minimal use of raw materials, proper energy utilization, increasing of product life, the use of recyclable or reusable products and the reduction of toxic, flammable or explosive materials, to meet or exceed regulatory targets. Product and process design can apply DfE techniques to achieve industrial ecology. The goal is to make minimum use of natural resources as well as to reduce harmful emissions to the environment (Francisco Junior et al., 2003).

According to Borchardt et al. (2012), the design should present solutions to the product life cycle; it should consider production, packing use, parts replacement and final disposal. Regarding textile products, environmental friendly clothing are made of sustainable resources. To produce sustainable clothes, DfE should consider the sustainable use of raw materials, sewing parts, distribution channels, stores, reverse logistics and waste (Eryuruk, 2012).

Borchardt et al. (2012) used DfE to evaluate the practices adopted in research and development of new products in a chemical industry and found that the product and process characteristics and the waste generation were the most important features to improve. The focus should be product and process characteristics together with waste minimization. Borchardt et al. (2010) also used DfE in manufacturing of shoe parts and achieved process cost reduction besides minimizing the use of raw materials and chemicals, generating benefits to the environment.

Denim fabrics are made of cotton using twill pattern (diagonal construction fabric). They are produced by interlacing raw weft yarns (horizontal fabric yarns) and died warp yarns (set of longitudinal yarns). The aging appearance is an important feature; it is caused by the fabric warp yarn fading in each wash (BNDES, 1999). To produce this pattern, the weft ends are wasted from the sides of the fabric, besides the warp waste, which are used to produce the false selvedge to stabilize the fabric before being cut. The energy consumption comes mainly from the weft insertion process and the heald frame drive. These fabrics can be made by different kinds of weaving technologies. Johansson (2002) points out that the environmental impact varies depending on the technology used, and according to Riitahuhta et al. (1994) the technology used in a product is vital to its environmental performance and therefore the environmental aspects should be part of establishing a company’s technological strategy.

Environmental and Economic Advantages

For Giannetti et al. (2008) there are a number of ways to make economic and environmental improvements simultaneously. To optimize material consumption, use of energy and other natural resources it is necessary to know in details the production process (Muncka et al, 2013). This study assesses in details two different production processes in order to understand the economic and environmental differences between them to produce denim fabrics.

Paoli et al. (2013) brought significant results of economic and environmental gain using DfE for wind turbine projects, by reducing costs and maximizing resources use, while Eryuruk (2012) lists the important environmental and economic benefits through textile reuse and recycling. Oliveira Neto et al. (2010, 2011, 2014) evaluated economic and environmental gains resulting from DfE utilization in a rubber factory, in a glass plant and in an automotive industry. Oliveira Neto and Sousa (2014) did the same in a supermarket retailer. Other authors have written about energy gain in textile industry, including weaving factories (Hasanbeigi and Price, 2012; Martínez, 2010), but there are no reports in scientific literature related to environmental gains of different weft insertion technologies, what becomes a research gap explored by this paper.

METHODS

To become an additional tool in the decision-making process for denim weaving industries regarding future investments in renewal and/or expansion of their factories, this paper assesses natural resource use, like cotton yarn, besides energy consumption in two different kinds of weft insertion technologies in weaving. Hence, its central objective is to compare if there is a difference in optimizing energy and material consumption between two systems, since according to Mendonça and Baxter (2001), DfE provides cost savings and environmental impact once it targets to minimize waste generation and raw materials use. Therefore, the following research question was posed: "Is there environmental and economic advantages resulting from the utilization of air jet over rapier weft insertion in denim production?"

To answer this question, a case study was conducted in a denim producer textile company, which is among the five largest denim producers in Brazil and operates with two different denim-weaving technologies in parallel. Semi-structured interviews were used for data collection due to unpredictability of data to be collected in the field and to address more freely the issues perceived during the discussions (Marconi and Lakatos, 2010). A case study was used because according to Cauchick Miguel and Sousa (2012) it is the most appropriate research method for a situation where a detailed analysis of one or more research objects is desired. In addition, case studies are suitable for exploratory research where performance practices between different organizations will be assessed (Yin, 2010). In the present study, however, it is intended to compare performance practices of different technologies within an organization. As the type of research was exploratory, a single case study was enough according to Yin (2010). Moreover, a cross sectional case study was performed, because according to Kumar (2011) it focuses on the study object only once.

The research initial part comprised an interview with the company's director. General company data, environmental management profile, production data, type of machinery, number of machines, fabric style characteristics and the main costs and wastes resulting from two weaving process were obtained. In addition, at this stage the financial data related to yarn and energy cost were collected. In a second stage, there was an interview with the plant manager, followed by a plant tour, where product data, energy consumption, production, raw material consumption and other relevant operational data for the research were checked.

To evaluate the economic and environmental advantages resulting from the two weaving technologies, this paper uses the approach proposed by Oliveira Neto et al. (2010) that encompasses three stages: data collection, economic assessment and environmental evaluation. In the first stage, data collection, the amounts of resources and emissions that were used in the two weaving technologies were measured by their mass. Further the mass balance was developed, to calculate the quantity of materials in yarn Kg and energy kWh to achieve monthly production in each technology in order to quantify the resource total usage. The second stage is the economic assessment where the revenues and costs are identified to determine the economic values of each weaving alternative. Phase three evaluates the environmental impact resulting from the resources employed in each weft insertion process. For this appraisal, this study employs the MIPS (Material Input per Service Unit) concept, developed by the Wuppertal Institute, which can evaluate the environmental changes allied to resource removal from Nature (Wuppertal Institute, 2014). MIPS refer to the entire life cycle of a product, from cradle to grave (Aoe and Michiyasu, 2005). This calculation identified the amount of material in the biotic, abiotic, water, air and erosion compartments, which are caused by the consumption of raw material (cotton) and electricity. This calculation is the result of the amount consumed multiplied by the intensity factors – MIF (mass intensity factors) as defined by Wuppertal Institute (2014). As a result, MIPS is obtained by multiplying the resource mass by its respective MIF per compartment, as per equation 1.

$$MIPS = Mass \times MIF_{Biotic} + Mass \times MIF_{Abiotic} + Mass \times MIF_{Water} + Mass \times MIF_{Air} \quad (1)$$

The MIF factors used in this work are shown in table 1. For cotton, the United States production data was used and for electricity the world average was employed. This study deals only with items produced in Brazil, but this does not prevent the utilization of this proposed calculation method, because the amounts are similar according to Oliveira Neto et al. (2011).

Table 1 – Material Intensity Factors used in this work

Consumption Items	Abiotic Material	Biotic Material	Water	Air	Erosion
Cotton (Kg/Kg)	8.600	2.900	8,814.0	2.740	5.010
Electricity (Kg/kWh)	1.550	0.000	66.730	0.535	0.000

Source: Wuppertal Institute (2014)

The sum of each compartment results is the Mass Intensity per Compartment (MIC). Then, to evaluate the total intensity factor provided by each technology the Mass Intensity Total (MIT) was calculated, which is the sum of all compartments.

CASE STUDY

To investigate the two denim-weaving technologies and their economic and environmental influence in a real context, a detailed case study was carried out, as stated before.

Process Description

This textile company under study provides constant investment in equipment renewal and expansion, and became a vertically integrated company, which produces from yarn to finished fabrics. Sustainable development, continuous process improvement, quality and productivity, minimization of natural resources use and reduction in waste generation are between the main company concerns, because besides the economic and environmental gains they are source of competitive advantage. It has ISO 9000 and ISO 14001 certifications.

They use two kinds of weft insertion technologies in the weaving process: air jet and rapier weft insertion. Through this study a careful comparison of the two systems were analyzed in order to provide the company a valuable decision-making tool for future technology transfer. Because it is a vertically integrated company, its manufacturing process involves the steps shown in Figure 1.

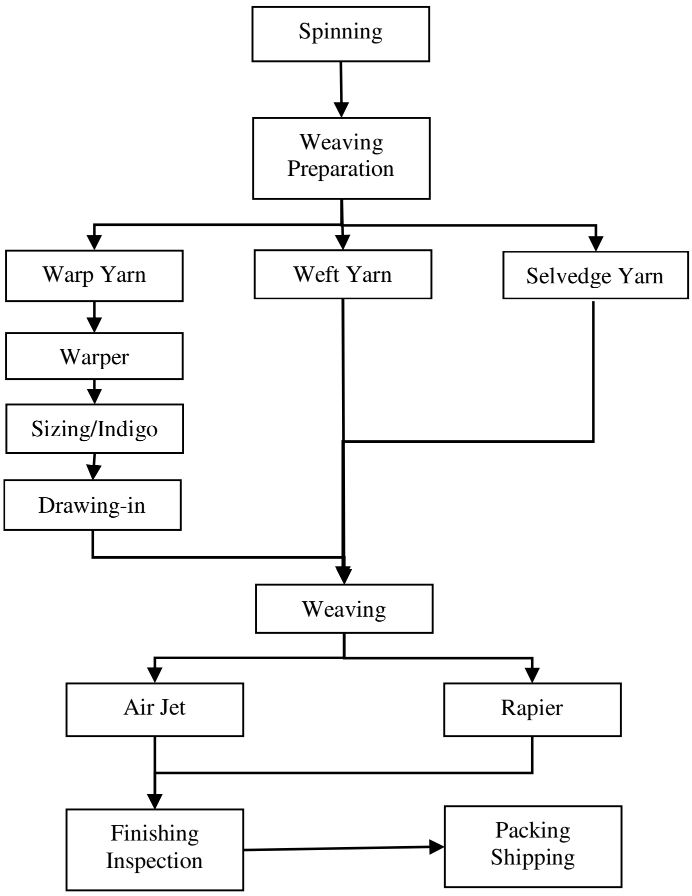

Figure 1 – Process flow chart

The spinning sector is responsible for yarn production to supply part of the current company needs. The balance is bought from the market. In the weaving preparation, the yarns are separated according to its end use into warp, weft, and selvedge yarns. Warp yarns move to a process called warping, which consists in changing commercial packages into warp beams. Next, the yarns in warp beams move to the indigo machine, where they will be dyed and sized. This process provides color and creates a covering film to protect yarn against tensions and frictions they will be submitted in the weaving stage. Then the drawing-in of the warp yarns into droppers, headles and reels is done.

There are two different processes in weaving. Fabrics can be made through air jet insertion or rapier insertion looms. In the weaving process, warp, weft and selvedge yarns are interlaced to produce the indigo fabric. After weaving, fabric passes through finishing process to be scoured, gain dimensional stability, softness and luster. Moving forward, fabrics are inspected to chck their quality characteristics. Finally, fabrics are cut, packed in commercial length bobbins and separated for shipment to customers.

Analysis and Discussion

As the weaving sector is the research object, it is necessary to set the process inputs and outputs in order to quantify the data and finish the first stage: data collection. Table 2 shows the denim style specification used in the case study:

Table 2 – Object Style Specification

Description	Style X
Pattern	3x1
Reed width (cm)	185
Finish width (cm)	167
Warp material	Cotton (CO)
Warp yarn count	10 Ne
Warp density	26 / cm
Weft material	Cotton (CO)
Weft yarn count	7 Ne
Weft density	16.5 / cm
Warp shrinkage	2%

The same style production was considered for both weaving technologies. Therefore, the process outputs were the same, that is, style X produced by the two kinds of weaving technologies. Thus, the variables were quantified in linear meters produced, using for comparison a 4,000,000 linear meters/month using the two different technologies. Cotton, electricity and compressed air were considered process entries. A workload of 720 hour/month was considered. Loom operational speeds to produce this style is different from one technology to the other due to each machine construction characteristics. Air jet weaving looms produce at 880 RPM while rapier machines run at 490 RPM.

Every time a weft yarn is inserted to interlace the warp yarns, it leaves ends on both fabric sides. These ends are cut after selvedge formation, being kept tensioned until cut. In Rapier machines, weft ends on both fabric sides. Because of machine characteristics, it is necessary that both weft ends are kept tensioned so that the rapier is able to take them up again at the next insertion. Air jet looms form weft ends only in one of the fabric sides. Consequently, air jet machine waste for weft yarn is 8 cm per insertion, while the waste generated by rapier machines is 14 cm per insertion.

According to the information obtained from the plant manager in the interview, yarns used to produce discharged false selvedge count for 10 weft yarns in air jet machines and 40 weft yarns in rapier machines. The production efficiency is 91% and 89% for air jet and rapier machines respectively. Energy consumption is 4 kWh/machine and 8 kWh/machine. However, air jet machines use compressed air to operate and the energy consumption in the compressors is equivalent to 7 kWh/machine. Rapier machines do not use compressed air. With this data, the next stage was the electricity and yarn consumption calculation for the two technologies as shown in table 3.

Table 3: Mass balance per month

Description	Style X in air jet loom	Style X in rapier loom
Weft yarn (Cotton)	1,094,214 Kg	1,127,591 Kg
Warp yarn (Cotton)	1,137,520 Kg	1,144,600 Kg
Total cotton yarn	**2,231,734 Kg**	**2,272,191 Kg**
Machine electricity	500,000 kWh	1,571,429 kWh
Compressor electricity	875,000 kWh	0 kWh
Total electricity	**1,375,000 kWh**	**1,571,429 kWh**

It is possible to note in table 3 that air jet looms consume a lower quantity of both resources for the same amount of fabric produced. This information agrees with Johansson (2002) statement that manufacturing technology influences the environmental impact.

Weft and warp yarns have different count, that is, a different mass volume for the same yarn length. The costs for the two kinds of yarns are different. According to the interviewee, weft yarns cost USD 3.06/Kg and warp USD 3.60/Kg. Electricity price is USD 0.15/kWh. Direct labor is the same for both technologies; therefore, it was not used in the comparison. Indirect manufacturing costs are allocated to products in direct proportion to workmanship, hence not interfering in the assessment performed. Based on those values it was possible to calculate the economic impact of both technologies as shown in table 4.

Table 4: Economic assessment on monthly consumption

Description	Style X in air jet loom (USD / Month)	Style X in rapier loom (USD / Month)
Cotton yarn cost	7,443,367.00	7,570,989.00
Electricity cost	206,250.00	235,714.00
Total monthly consumption	**7,649,617.00**	**7,806,703.00**
Monthly economic gain	157,086.00	-

There are economic benefits in using air jet insertion technology over rapier technology, as shown on table 4. This confirms the findings by Eryuruk (2012) who used DfE in textile production design and found that air jet technology minimizes electricity use, generating economic gain . However, is there any relation of this gain with environmental impact?

To check this, it was necessary to compare environmental impact resulting from each technology, using MIPS concept as described in the Methods section. For that purpose, the mass balance identified in table 3 was multiplied by the respective MIF shown in table 1, applying equation 1 above. The results are summarized in table 5.

Adding up each compartment value for each technology the Material Intensity Total (MIT), was obtained, which is the sum of all MIPS for all compartments. The MIT for air jet weaving machines was 15,344 tons/month, while the MIT for rapier weaving machines was 15,634tons/month. There is a 289 tons/month gain for materials not extracted or modified from the environment in using air jet looms in relation to rapier looms.

Table 5: MIPS on denim weaving process tons/month

	Abiotic Material (Kg)	Biotic Material (Kg)	Water (Kg)	Air	Erosion
Air jet loom					
Cotton	19,193	6,472	15,207,035	6,115	11,181
Energy	2,131	0	91,754	736	0
Total air jet	**21,324**	**6,472**	**15,298,789**	**8,851**	**11,181**
Rapier loom					
Cotton	19,541	6,589	15,482,710	6,226	11,384
Energy	2,436	0	104,861	841	0
Total rapier	**21,977**	**6,589**	**15,587,572**	**7,067**	**11,384**

This calculation method for MIPS (Material Input per Service Unit) was also used by Spinelli et al. (2013) to check how much water, abiotic material and air was necessary for biodiesel production from sunflower seeds. Federici et al. (2008) used it to compare transportation systems to indicate the best solution to move people and cargo in Italy.

CONCLUSION

The results obtained in this work enabled the researchers to conclude that there are economic and environmental gains in using air jet insertion weaving technology in comparison to rapier insertion for denim production. In parallel, the results obtained herein bring some contributions to theory and practice. To the body of knowledge of Operations Management, this work fulfills a gap in the literature since there were no reports in scientific writings related to environmental gains of different weft insertion technologies for fabric manufacturing. The utilization of the MIPS concept also provided an additional contribution in that direction. On the practical side, this study can be used as an additional tool for the practitioner decision-making process when evaluating comparable technologies for textile production. The determination of the environmental impact of each technology could be a valuable instrument to allow an adequate technology choice in the manufacturing sustainability enhancement.

As a main restriction, the results obtained in this research cannot be generalized because they were obtained as a result of a single case study. Therefore, as a suggestion for future studies, a larger number of companies, considering other variables and different kinds of technologies could be considered.

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