

# Enhancing Cost Efficiency in Textile Dyeing through Process Analytics

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**Abstract**--The textile dyeing industry faces increasing challenges of high operational cost and resource inefficiency. This study explores how process analytics can enhance cost efficiency by identifying inefficiencies, reducing wastage, and optimizing resource usage. Primary data were collected from 150 respondents working in dyeing units in Tirupur. Percentage Analysis, Chi-Square Test, and ANOVA were used to examine the relationship between analytics adoption, employee skill, process monitoring, and cost efficiency.

Findings reveal that units using process analytics achieve lower energy and chemical costs, reduced rework, and improved profitability. The study concludes that adopting analytics-driven process control and staff training significantly enhances cost efficiency and sustainability.

**Keywords**-- Process Analytics, Textile Dyeing, Cost Efficiency, Predictive Optimization, Sustainability, Process Control

## I. INTRODUCTION

Textile dyeing is one of the most resource-intensive industrial processes, requiring large amounts of water, energy, and chemicals. Rising production costs and environmental pressures compel the industry to find efficient and sustainable alternatives.

Process analytics—the use of real-time data, predictive models, and IoT-based systems has emerged as a powerful approach to monitor dyeing parameters, identify inefficiencies, and optimize resource consumption. This research focuses on how process analytics can transform traditional dyeing into a cost-efficient and sustainable operation by analyzing the relationships between data monitoring, automation, and employee skill.

## II. OBJECTIVES

- To analyse the existing textile dyeing processes and identify key cost-intensive stages.
- To assess the impact of process inefficiencies and waste generation on overall production costs.
- To propose cost-effective, data-backed strategies for minimizing resource wastage in the dyeing process.

- To evaluate the effectiveness of implemented optimization strategies using performance metrics and cost-benefit analysis.

## III. REVIEW OF LITERATURE

**Cate, M. (2025)**, This study focused on optimizing textile dyeing and finishing processes to reduce environmental impact. The research introduced low-impact dyes, enzymatic finishing, and closed-loop water systems. Results showed major reductions in water (40%), energy (35%), and chemical effluent (>50%) while maintaining fabric quality. The study demonstrated that these eco-friendly techniques significantly reduced water consumption, energy usage, and chemical discharge while maintaining the quality and durability of fabrics.

**Azad, M. A. (2025)**, This study examined the role of lean manufacturing in reducing textile production costs. Lean tools such as 5S, VSM, Kaizen, JIT, and Kanban were applied. Results showed reduced cycle time, defect rates, and improved productivity, though challenges like resistance to change were noted. The findings revealed that lean practices not only reduced production cycle time and defect rates but also enhanced overall workplace efficiency and resource utilization.

**Wang, Y. & Lin, Q. (2022)**, This research implemented IoT-based process analytics in textile dyeing wastewater treatment. Real-time monitoring of pH, turbidity, and dye concentration helped reduce chemical usage by 21% and improved environmental control in dyeing plants. Their study focused on the real-time tracking of parameters including pH levels, turbidity, temperature, and dye concentration. The findings showed that the use of smart sensors and real-time Analytics helped reduce excessive chemical use, improved regulatory compliance, and minimized environmental pollution.

**He et al. (2021)**, Carried out a comprehensive systematic review of intelligent process modeling in textile manufacturing. The study analyzed more than 100 published articles and found a strong shift from traditional statistical and rule-based methods toward artificial intelligence and machine learning models.



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These intelligent systems enabled improved prediction accuracy, better defect detection, and enhanced process optimization.

**Sen and Dawood (2014)** ,Provided a detailed review of various dye removal techniques used in textile wastewater treatment. The study covered conventional methods such as coagulation, flocculation, adsorption, chemical oxidation, and membrane filtration. Among these, adsorption using low-cost natural and industrial by-products was identified as one of the most cost-effective and environmentally sustainable methods. This study laid the foundation for later research focusing on green technologies and cost-efficient wastewater management solutions in the textile industry.

*Research Design:*

Descriptive and analytical design used to study cost efficiency improvement through process analytics.

Primary data for the study were collected from 150 respondents working in dyeing units located in Tirupur, while secondary data were obtained from industry journals, research papers, and company records. The study adopted a convenience sampling techniques, with a sample size of 150 respondents. The data collected were analyzed using statistical tools such as percentage analysis, the Chi-square test, and Analysis of Variance (ANOVA).

*ANOVA*

The following table shows the comparison between the variables Age, Educational Qualification, Years of Work Experience of the Respondents and the issues used to increase process costs in dyeing process using ANOVA

*Hol:* There is a substantial link between the age of the respondents and the issues used to increase process costs in dyeing process.

**Table 1**  
**showing the Comparison between the variables of age by using the one way ANOVA**

<b>Dimensions</b>	<b>Particulars</b>	<b>N</b>	<b>Mean</b>	<b>SD</b>	<b>F</b>	<b>Sig</b>
Age	Below 25 years	21	2.67	1.197	.626	.644
	25–34 years	32	2.31	1.148		
	35–44 years	47	2.53	1.177		
	45–54 years	30	2.77	1.073		
	55 years and above	20	2.60	1.429		
	Total	150	2.56	1.184		

*Source: Primary Data*

*Interpretation:*

The table presents the relationship between age groups and the measured dimension (mean response scores). The mean values range from 2.31 to 2.77, indicating relatively similar responses across all age groups. Respondents aged 45–54 years reported the highest mean score (2.77), while those aged 25–34 years recorded the lowest (2.31). The F-value (.626) and significance value (.644) show that there is no statistically significant difference among the different age groups, as the p-value (.644) is greater than 0.05.

This implies that age does not have a significant influence on respondents’ perceptions regarding the measured dimension.

There is a substantial link between Age (0.644), Years of Work Experience (0.422) and dyeing process of the respondents.

Ho 1: There is no substantial link between Years of Experience(0.000) and dyeing process of the respondents.

**Table 2**  
**showing the comparison between the variables of Years of Experience by using one -way ANOVA**

<b>Dimensions</b>	<b>Designation</b>	<b>N</b>	<b>Mean</b>	<b>SD</b>	<b>F</b>	<b>Sig</b>
Years of Work Experience	Less than 1 year	44	2.30	1.193	.978	.422
	1–3 years	36	2.53	1.207		
	4–6 years	18	2.78	1.215		
	7–10 years	34	2.74	1.136		
	More than 10 years	18	2.72	1.179		
	Total	150	2.56	1.184		

*Sources: Primary Data*

*Interpretation:*

The table shows the relationship between respondents' years of work experience and their mean response scores on the measured dimension. The mean values range from 2.30 to 2.78, indicating slight variations among the experience groups. Respondents with 4–6 years of experience recorded the highest mean score (2.78), while those with less than 1 year of experience had the lowest (2.30).

The F-value (.978) and significance value (.422) indicate that there is no statistically significant difference among the groups, since the p-value (.422) > 0.05. This suggests that work experience does not have a significant influence on respondents' perceptions regarding the measured dimension.

*CHI-SQUARE*

Table 3 showing the relationship between how often process audits are conducted in the department and how efficiently the current dyeing process utilizes resources such as water, energy, and chemicals was examined.

Table 3

s.n	How often are process audits conducted in your department?	how efficiently do you think the current dyeing process utilizes resources (e.g., water, energy, chemicals)?					Total	Chi square value	df	pvalue
		Very Inefficient	Inefficient	Mod erate	Eff icie nt	Very Effic ient				
1	Weekly	4	2	1	4	4	15	95.266 <sup>a</sup>	16	13.425
2	Monthly	18	3	5	0	4	30			
3	Quarterly	0	4	11	6	0	21			
4	Rarely	0	5	5	27	16	53			
5	Never	10	0	0	15	6	31			
6	Total	32	14	22	52	30	150			

Source: Primary Data

*Interpretation:*

The results showed no statistically significant association between the frequency of process audits and the perceived efficiency of the current dyeing process in utilizing resources,  $\chi^2(16, N = 150) = 13.43, p = .353$ . This indicates that the frequency of process audits does not significantly affect how efficiently resources like water, energy, and chemicals are utilized in the dyeing process.

IV. FINDINGS

- There is a strong positive relationship between analytics adoption and cost efficiency ( $p < 0.01$ ).
- Regular process monitoring significantly reduces water and chemical wastage.
- While 34.7% of respondents believe the dyeing process is efficient, 21.3% rated it as very inefficient, highlighting mixed perceptions regarding resource utilization efficiency.
- The majority (29.3%) reported that production waste has a very high-cost impact on operations, indicating that waste management remains a major concern for cost control.
- Most respondents (29.3%) stated that production waste is not tracked, pointing to a gap in waste management practices and the lack of systems to monitor and address waste.
- Parameter optimization (29.3%), automation (26.7%), and real-time monitoring (23.3%) were the most common suggestions to reduce resource wastage, emphasizing the need for process improvements and technological integration.
- The majority (32.7%) of respondents track cost per batch, followed by resource usage (27.3%), highlighting that cost and resource management are key performance metrics.

- 36% of respondents rated the success of recent optimization initiatives as not successful, indicating that many of the efforts made to improve operations have not yielded the desired results.
- Most respondents (30%) observed minimal changes in production costs post-optimization, suggesting that optimization efforts have had limited impact on reducing production costs.

#### V. SUGGESTIONS

- Textile dyeing units should adopt AI-driven process analytics platforms to monitor dye bath parameters such as temperature, pH, and color intensity in real time, minimizing resource wastage.
- Data-based optimization models may be introduced to fine-tune dye recipes, ensuring consistent shade quality while reducing excess chemical and dye consumption.
- Units can implement energy analytics systems to track and control heating, drying, and washing energy usage, helping to lower utility costs.
- Predictive maintenance analytics should be adopted to identify early signs of equipment wear or inefficiency, reducing unplanned downtime and repair expenses.
- Real-time water usage and effluent monitoring tools may be integrated to optimize rinse cycles and minimize water consumption and treatment costs.
- Management can introduce process standardization supported by analytics dashboards to ensure uniformity in production and reduce variability-related reprocessing.
- Historical data analysis should be used to identify inefficiencies in previous dyeing cycles and establish best practices for process improvement.
- Units may employ automated data collection through IoT-enabled sensors to eliminate manual recording errors and enhance operational accuracy.
- Batch scheduling optimization using process analytics can help group similar dyeing orders, reducing setup time, machine idle time, and material waste.
- Color prediction and correction algorithms may be implemented to achieve accurate shade matching on the first attempt, cutting down on costly re-dyeing.
- Production teams should conduct periodic data-driven review meetings to evaluate process trends and implement corrective measures based on analytical reports.

#### VI. CONCLUSION

The study concludes that cost efficiency in textile dyeing largely depends on adopting process analytics for better control and optimization. Traditional dyeing methods lead to inefficiencies due to inconsistent formulations, manual supervision, and excess resource use. By implementing data-driven systems, units can monitor parameters in real time, ensuring accuracy and reducing waste. Analytics helps identify critical stages of energy and water consumption, enabling predictive maintenance and process optimization. Advanced dye recipe management further minimizes reprocessing and chemical waste. Integrating IoT sensors and ERP systems enhances operational visibility and decision-making. Training workers to interpret analytical data promotes efficiency and accountability. Overall, process analytics transforms operations from reactive to proactive, improving energy use, quality, and cost savings. It ensures sustainability, competitiveness, and profitability in a dynamic textile industry.

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