

Multivariate Analysis of Interaction Effects in Single-Factory Apparel Production: Efficiency, Overtime, and SMV

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Abstract

This research analyzes the multivariate relationships between Efficiency, Overtime, and SMV (Standard Minute Value) in the garment production process at X Fashions Limited over six months of continuous data. The study focuses on identifying the interaction effects between these key variables across various production lines. Using statistical methods, including correlation analysis, ANOVA, and regression models, the research reveals complex and varied patterns in the relationships between efficiency, overtime, and SMV. The results indicate that while higher efficiency generally correlates with reduced overtime, this relationship is inconsistent across production lines, with some lines showing weak or no correlation. Similarly, the correlation between SMV and overtime is mostly negative, suggesting that higher SMV tends to reduce overtime, though line-specific operational factors introduce variability. The study also highlights that the relationship between Efficiency and SMV differs across lines, with some showing weak positive/negative correlations. These findings underscore the importance of line-specific interventions for optimizing efficiency and reducing overtime. The research contributes to a better understanding of how operational practices, resource management, and SMV adjustments impact production outcomes, offering actionable insights for improving productivity at X Fashions Limited. Future work should explore real-time monitoring systems to dynamically adjust SMV based on production line performance.

Keywords

Production Efficiency, Standard Minute Value (SMV), Overtime Management, Manufacturing Optimization, Multivariate Analysis

1. Introduction

Ready-Made Garment (RMG) industry contributes considerably to national economy and underlines its importance as the biggest exporting industry in Bangladesh (Islam, 2023; Md. T. Rahman et al., 2017). It is the greatest trade earner, bringing in over 80 percent of the entire exports in the country (Islam, 2023; K. M. Rahman & Chowdhury, 2020). Garment industry is a very competitive industry in the world today and the issue of efficiency of production and its cost containment is very crucial in ensuring the sustainability and growth of business. Some of the most important KPMs, Efficiency, Overtime, and Standard Minute Value (SMV) are important in ensuring that the production managers are able to maintain the quality of products, optimally utilize labor and ensure that operational costs are kept under control. Efficiency refers to the effectiveness with which production resources are utilized in order to achieve the planned production over a specific time frame. Overtime is also an indicator of inefficiency in the process in addition to leading to increase in the overall production costs. It is a factor affecting productivity within the apparel factories because it causes misalignments between productivity per employee and productivity per work hours (Slović et al., 2016a). The Standard Minute Value (SMV) is a unit of measurement used in the apparel manufacturing

industry to describe the number of minutes it takes to complete a particular job (Bizuneh & Omer, 2024a). This measure serves as a critical basis for labor planning and evaluating performance in the garment sector.

Over the past few years, apparel manufacturers have been under increasing pressure to be effective and at the same time reduce the use of overtime. In apparel manufacturing, production delays and inefficiencies can result in excess inventory and higher costs, including overtime expenses (Cabrejos-Paredes et al., 2021). In order to remain competitive, the garment manufacturers are now shifting the product making competition towards speed and not on quality and scale as before. This change raises the importance of enhancing manufacturing performance at the same time as maintaining its costs (Sun et al., 2021). They are also pressured to do away with wastage and improve productivity at reduced costs, which directly responds to the requirement of better efficiency (C, 2018). This challenge becomes even more complex because of variations in the performance in production lines. Differences in productivity per employee and total work hours can be attributed to overtime and inefficiencies, which negatively impacted overall productivity in the apparel production sector (Slović et al., 2016b). Differences in operational practices, worker skill levels, and the reliability of equipment can greatly influence how efficiency, SMV, and overtime interact with one another.

Previous research has examined these variables using diverse methods. Jalil et al. (2015) conducted work studies and experimental investigations, while Bizuneh and Omer (2024b) applied value stream mapping and lean tools. More recent approaches include implementing an Improved Particle Swarm Optimization neural network by Shen & Ji (2024), and developing an IoT-based system using weight sensors and NodeMCU (Alex, 2022). However, research examining the multivariate interactions among these factors, especially within the context of apparel manufacturing remains limited.

Our study aims to fill this gap by examining the multivariate relationships between efficiency, overtime, and SMV across several production lines of a single apparel factory. Although garments manufacturing is one of the most important sectors in Bangladesh, limited research has been conducted on the interaction between SMV, efficiency, and overtime in this context. Most factories continue to operate in traditional ways, without adopting data-driven approaches for performance optimization. Moreover, no prior studies have specifically examined these relationships within the case company analyzed in this research. Addressing this gap can provide a foundation for future studies and guide improvements in production management practices across the industry. To address these gaps, the present study formulates the following research questions:

1. What is the nature of the relationship between Standard Minute Value (SMV) and overtime, and does this relationship consistently hold across all production lines?
2. To what extent does the effect of production line efficiency on overtime depend on the specific production line?
3. How do SMV and efficiency interact, and what does the variability in this relationship reveal about line-specific operational dynamics?

1.1 Objectives

The main objectives of this study are outlined below:

1. Examine the relationship between Standard Minute Value (SMV) and overtime across different production lines.
2. Investigate how production line efficiency influences overtime, and whether this effect varies across lines.
3. Analyze the interaction between SMV and efficiency to uncover line-specific operational patterns.
4. Use multivariate analysis to identify key factors that can guide efficiency improvements and reduce overtime in the garment factory.

2. Literature Review

The apparel industry in emerging nations is a major export. The need for clothes is expanding as people's fundamental necessities rise, as does the world population. Even while garment manufacturing rises over time, the rate of growth is insufficient to meet rising demand. In 2005, the World Trade Organization phased down the textile and apparel quota system, allowing many poor and small export-oriented nations to enter industrialized countries' marketplaces. The present economic slump has reduced demand for garment exports, resulting in enormous unemployment in emerging nations. China, Bangladesh, India, and Vietnam are all key players in this market. For the majority of emerging nations, the garment sector is the fundamental stepping stone towards industrialization. Due to low entry barriers and high pay rates, the bulk of rich countries import clothes from emerging economies. The textile and garment sector is one of the most labor-intensive of all other industrial businesses (Jayawardena, 2020). Since the late 1970s, Bangladesh's RMG business has developed predominantly as an export-oriented industry, with the domestic

market for RMG expanding rapidly as personal disposable income has increased and lifestyles have changed. The sector quickly became significant in terms of employment, foreign exchange revenues, and contribution to GDP. Bangladesh's RMG industry is often overlooked in the competitive market due to its cheap labor costs (\$0.11 per shirt in Bangladesh, \$0.26 in India, and \$0.79 in Sri Lanka) (Shumon et al., 2010).

The Standard Minute Value refers to the time necessary to execute a task or activity using a standard technique and efficiency under certain conditions (Habibur Rahman et al., 2014). Standard time is a standard language for fashion firms and manufacturers to communicate pricing, timelines, and floor capacity. Managers must understand the time necessary to produce a new product to increase production, fulfil customer requests, and maintain competitiveness during order acceptance. Accurate forecast of SMV has a direct influence on product quoting, production planning, resource optimization, and cost control. Accurate SMV is crucial for developing manufacturing planning, forecasting, pricing, and other technical and administrative tasks in a corporation (Eraslan, 2009). The issue for apparel producers and management is to effectively produce high-quality clothes that match client demand while being cost-effective (Lu & Karpova, 2011). Currently, engineers estimate SMV using their experience, time and motion studies, and formulas based on past research. This allows them to compute cycle time based on a comprehensive production process. Traditional approaches are costly due to the need for professional supervision of each step. Even little mistakes can impact the overall SMV. Using improved methods to measure SMV can help firms cut costs and increase production efficiency. Saving one minute per product can lead to large annual earnings, providing other circumstances stay constant over time (Shao et al., 2022).

Workers sometimes work overtime to offset high living expenses. Workers often labor extra to satisfy supplier demands on time. Bangladeshi labor legislation (2006) specifies a typical workday of eight hours per day, six days per week. 48 hours a week is considered a work week, which can be extended to 60 hours with overtime. Bangladeshi garment workers work an average of 76 hours per week, which is significantly more than the usual workweek. According to the Labor Act of 2006, workers shall get payment within 7 working days of completion. Unfortunately, many factories fail to adhere to this standard. In Bangladesh, just 30% of the industry's net profit is spent on wages, compared to the global average of roughly 50% (K. M. Ayatullah Hosne Asif, 2017).

Efficiency is the ratio of useful work accomplished by a person, machine, or process to the total input received. Productivity measures output per unit of input. Workstations are in the garment sector, an ideal workstation should have minimal motion, travel, and waiting time, as well as an ergonomic design (Tareque et al., 2020). Efficiency can be lower in garments industry because of following reasons.

- Unavailability of maintenance operator during required time
- Operator took much more time to cuff folding operation
- Operator waste his production time to collect the thread waste

Using time study to improve operator efficiency and reduce machine waiting time leads to enhanced productivity. High employee motivation leads to higher productivity. Employees are motivated by various incentive programs based on efficiency, honesty, and production. The work study approach improves productivity in the sewing section. Motion studies enhance processes and procedures, reducing the number of stages involved. Time and motion analysis leads to more efficient utilization of people, machines, and resources. The personnel are very motivated (Subhashini & Varghese, 2021).

3. Methodology

3.1. Research Design

In this research, a quantitative form of analysis was used to examine the correlation among Efficiency, Overtime, and Standard Minute Value (SMV) in various production lines in X Fashions Limited. The comparative design was done at the line level and this could capture overall factory trends and line specific variations. The research method combines inferential tests, descriptive statistics and multivariate regression equations.

3.2. Statistical Tools and Theoretical Basis

a) Analysis of Variance (ANOVA):

To compare efficiency and overtime variations across production lines, one-way ANOVA was employed. ANOVA tests whether the means of different groups are statistically different. The general model is:

$$F = \frac{MS_{between}}{MS_{within}} \dots\dots\dots(1)$$

Where:

$$MS_{between} = \frac{SS_{between}}{df_{between}} \dots\dots\dots(2)$$

$$MS_{within} = \frac{SS_{within}}{df_{within}} \dots\dots\dots(3)$$

Here, Sum of Squares (SS) measures variation between and within groups. Degrees of freedom (df) represent the number of independent pieces of information available to estimate variability in the data. A statistically significant F-ratio indicates that at least one group mean differs from the others.

$$SS_{within} = \sum_{j=1}^k \sum_{l=1}^l (X - \bar{X}_f)^2 \dots\dots\dots(4)$$

Where:

- SS_{within} = variability among values inside each line.
- X = individual observed value of variables.
- \bar{X} = mean value of observed variables.

$$SS_{between} = \sum_{j=1}^k (\bar{X}_f - \bar{X})^2 \dots\dots\dots(5)$$

$$SS_{total} = \sum_{j=1}^h (\bar{X}_f - \bar{X})^2 \dots\dots\dots(6)$$

$$df_{within} = k - 1 \dots\dots\dots(7)$$

$$df_{between} = n - k \dots\dots\dots(8)$$

$$df_{total} = n - 1 \dots\dots\dots(9)$$

Where:

- n = total number of observations.
- k = number of production lines.

Compute the p-value:

The p-value is the probability that an F -value at least as extreme as the observed one could occur by chance if the null hypothesis is true.

$$p = P(F_{df_{between},df_{within}} \geq F_{observed}) \dots\dots\dots(10)$$

Where:

- $F_{df_{between},df_{within}}$ = F-distribution with numerator and denominator degrees of freedom.
- $F_{observed}$ = calculated F-ratio.

b) Post Hoc Analysis (Tukey's HSD):

When ANOVA revealed significant differences, Tukey's Honestly Significant Difference (HSD) test was conducted to identify pairwise group differences. Tukey's HSD is calculated as:

$$HSD = q_{\alpha,k,df} \times \sqrt{\frac{MS_{within}}{n}} \dots\dots\dots(11)$$

Where:

- $q_{\alpha,k,df}$ = standardized range statistic,
- MS_{within} = mean square within groups,
- n = sample size per group.

This test controls for Type I error across multiple comparisons and is widely recommended in production efficiency research.

c) Correlation Analysis:

Pearson's correlation coefficient was used to measure linear associations between variables:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \dots\dots\dots(12)$$

Where r ranges from -1 (perfect negative correlation) to +1 (perfect positive correlation). This helped identify whether higher SMV is associated with reduced overtime or improved efficiency.

d) Regression Models and Interaction Effects:

Ordinary Least Squares (OLS) regression was used to analyze the impact of targets, achievements, efficiency, and SMV on overtime. The general form of the regression model is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \epsilon \dots\dots\dots(13)$$

Where:

- Y = dependent variable (Overtime),
- X_1, X_2, X_3 = independent variables (Efficiency, SMV, Target),
- β = regression coefficients,
- ϵ = error term.

Interaction terms (e.g., Efficiency \times Line, SMV \times Line) were included to capture line-specific dynamics.

3.3. Analytical Software

All analyses were conducted using Python (pandas, statsmodels, scikit-learn). Visualization techniques (boxplots, scatterplots, marginal effects plots) were employed to complement statistical results and provide clear interpretation of line-level variations.

4. Data Collection

Data for this study were collected from a leading garment factory in Bangladesh. The full dataset spans two years of production operations, although analysis focused on a continuous six-month period of line-level data. It covers multiple production lines and records key variables such as line efficiency, overtime hours, Standard Minute Value (SMV), total production minutes, planned production targets, and actual output achieved.

The raw operational records were systematically cleaned and preprocessed to remove obvious errors and inconsistencies. For example, entries with missing or anomalous values were corrected or removed to ensure data quality. This preparation ensured that the dataset was of high quality and ready for robust statistical analysis.

5. Results and Discussion

5.1. Efficiency Variation Across Production Lines: ANOVA and Post-Hoc Analysis

The Tukey HSD results reveal critical efficiency differences between production lines, with clear patterns emerging. The results establish KA 601, KA 602 as top performers, with statistically indistinguishable efficiency ($p=0.999$) and significant advantages over other lines (e.g., +10.49 to +14.06 points vs KA 305/401, all $p<0.001$). KA 305 emerges as a clear underperformer, requiring 10.78–14.06% more input than KA 403/ KA 601 for equivalent output ($p\leq 0.003$, CIs excluding zero). KA 403 occupies a mid-tier position, outperforming KA 305 but lagging behind benchmarks. Non-significant differences among mid-tier lines (e.g., KA 301–304) suggest consistent but suboptimal processes. The hierarchy prioritizes urgent improvements for KA 305, standardization of KA 601/602 practices, and targeted upgrades for mid-tier lines. These findings provide a data-driven foundation for targeted interventions - prioritizing the largest gaps with the strongest statistical evidence. The analysis objectively identifies which lines need improvement versus which are performing adequately, enabling focused resource allocation for maximum productivity gains. The combined boxplots with rigorous statistical testing, ensuring reliable insights for factory optimization. Figure 1 distribution of production efficiency across manufacturing lines, measured as a percentage. Boxplots show

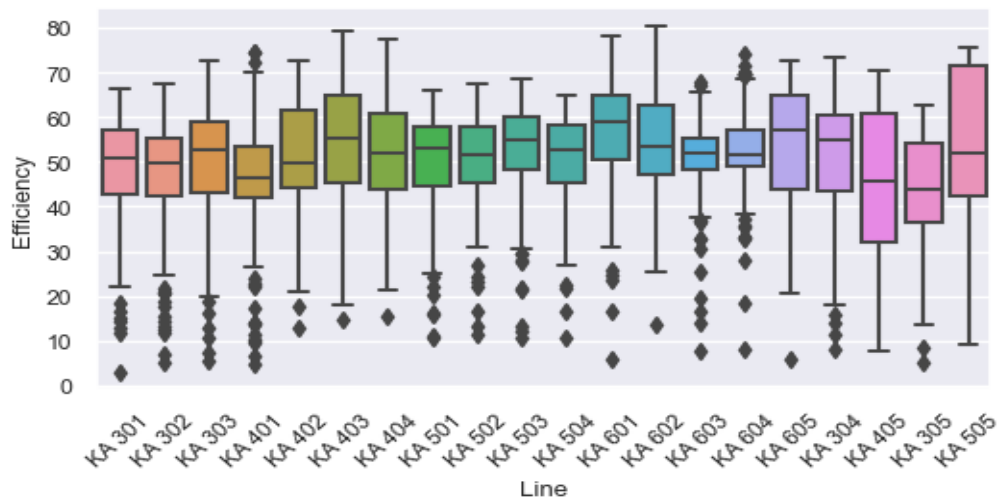


Figure 1. Efficiency Distribution by Production Line

median efficiency (center line), interquartile range (box), and full data range (whiskers). Lines are ordered by median efficiency, revealing performance variations critical for operational benchmarking. Notably, Line KA 601 demonstrates the highest median efficiency, while Line KA 305 shows the widest performance variability.

5.2. Line-Specific Correlation Between Production Minutes and Overtime

The correlation analysis between production minutes and overtime across different production lines shows a mixed pattern, with most relationships being weak or negligible. A few lines like KA 305 (0.11) and KA 401 (0.14) show slight positive correlations, meaning overtime tends to increase slightly as production minutes' rise. However, several lines, particularly KA 504 (-0.40), KA 605 (-0.41), KA 503 (-0.32), KA 304 (-0.32), and KA 602 (-0.33) display moderate to strong negative correlations, suggesting that higher production minutes actually lead to less overtime, possibly due to better workflow efficiency or optimized staffing (see Figure 2). Most other lines hover near zero, indicating little to no direct relationship. This variation highlights that overtime is influenced by more than just production volume, with line-specific factors like operational practices or resource management playing a key role.

5.3. Impact of Target and Achievement Percentage on Overtime

The analysis of Target vs. Achievement % impact on overtime shows that higher target values are associated with reduced overtime (coefficient = -3.60, $p = 0.023$), suggesting that setting higher targets may help in reducing overtime. The negative interaction (coefficient = -0.032, $p = 0.09$) suggests high targets slightly mitigate overtime penalties from overachievement, hinting at better workflow optimization in target-driven line (please see Table 1 and corresponding Figure 5). Conversely, higher Achievement% is positively associated with Overtime (coefficient = 93.32, $p < 0.001$),



Figure 2. Production Minutes vs. Overtime by Line

indicating that better achievement rates lead to increased overtime. However, the interaction between target and achievement % is not statistically significant ($p = 0.090$), suggesting that the combined effect of these variables on overtime is minimal. Table 1 and Figure 5 show that, target and achievement % have a limited impact on overtime. The model explains 22.2% of the variance in overtime, but issues such as autocorrelation (Durbin-Watson = 1.203) and multicollinearity (Condition Number = $8.22e+05$) point to the need for further model refinement to improve its accuracy.

Table 1. OLS Regression Results for the Impact of Target and Achievement Percentage on Overtime

Variable	Coefficient	Std. Error	t-value	p-value	95% Conf. Interval
Intercept	1733.5311	707.846	2.449	0.014	[345.44, 3121.62]
Target	-3.5977	1.583	-2.272	0.023	[-6.70, -0.49]
Achievement %	93.3185	8.924	10.457	<0.001	[75.82, 110.82]
Target × Achievement %	-0.0323	0.019	-1.695	0.090	[-0.07, 0.005]

$R^2 = 0.222$, Adj. $R^2 = 0.221$, Condition Number = $8.22e+05$ (potential multicollinearity)

5.4. Analysis of Efficiency-Overtime Interaction Across Production Lines

The analysis of the interaction effect between efficiency and overtime across production lines is statistically significant with an ANOVA test ($p < .05$), and the interaction between line and efficiency was also significant as well (F-statistic = 4.55, $p = 2.38e-10$), suggesting that the effect of efficiency on overtime differs across production lines. The highest average overtime is observed in the low-efficiency group, with values typically ranging between 5325 (KA 603) and 8704 (KA 304) minutes (see Figure 3). KA 304 has the highest average overtime (8704), while KA 603 shows the lowest (5325). The medium-efficiency group exhibits slightly lower overtime than the low-efficiency group. Lines like KA 301 (7379), KA 303 (7797), KA 304 (7456), and KA 404 (7860) still show relatively high overtime, while others like KA 603 (4349) and KA 605 (4714) have relatively lower overtime (Figure 4 and Figure 6). As efficiency increases, overtime tends to decrease (see Figure 5).

The High Efficiency group shows reduced overtime across most lines, with KA 305 (4724), KA 603 (4295), and KA 605 (3765) having the lowest average overtime, reflecting the impact of higher efficiency on reducing overtime. The Very High Efficiency group shows the lowest average overtime, with KA 603 having the smallest overtime (3354), followed by KA 605 (3753) and KA 601 (4209). This suggests that extremely high efficiency leads to the least overtime across most production lines (see Figure 4). The production lines KA 404, KA 505, and KA 602 exhibit concerning volatility where overtime fluctuates unpredictably regardless of efficiency levels.

KA 505 shows particularly illogical patterns, with its "High" efficiency group (7,111 minutes) requiring more overtime than lower efficiency groups. Similarly, KA 602's overtime paradoxically increases at higher efficiency levels (5,620 minutes for "High" vs. 4,578 for "Medium"), while KA 505 displays wide variations (2,871 to 7,111 minutes) across all groups. These erratic patterns suggest that severe operational instability is likely caused by inconsistent staffing, machine failures, or poor workflow design, which completely disrupts the normal efficiency-overtime relationship

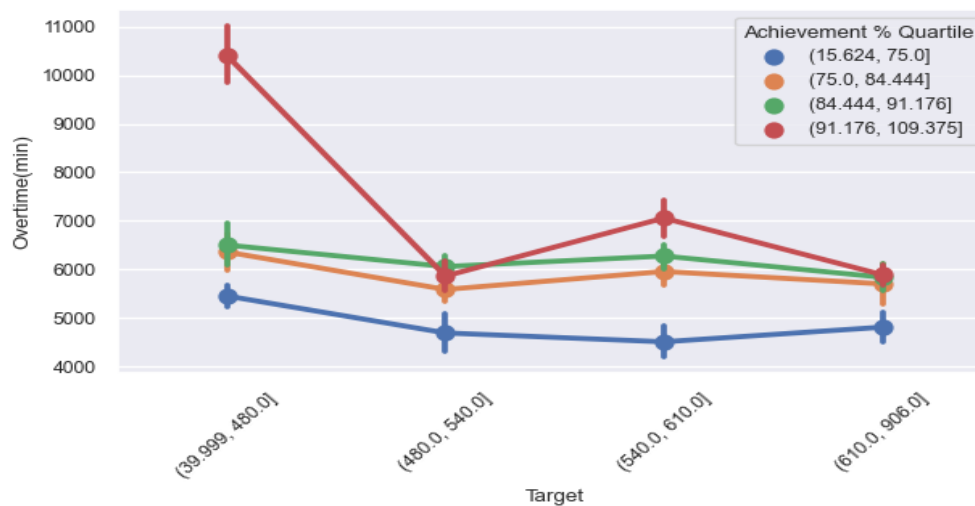


Figure 3. Interaction Between Target and Achievement % on Overtime

KA 505 shows particularly illogical patterns, with its "High" efficiency group (7,111 minutes) requiring more overtime than lower efficiency groups. Similarly, KA 602's overtime paradoxically increases at higher efficiency levels (5,620 minutes for "High" vs. 4,578 for "Medium"), while KA 505 displays wide variations (2,871 to 7,111 minutes) across all groups. These erratic patterns suggest that severe operational instability is likely caused by inconsistent staffing, machine failures, or poor workflow design, which completely disrupts the normal efficiency-overtime relationship

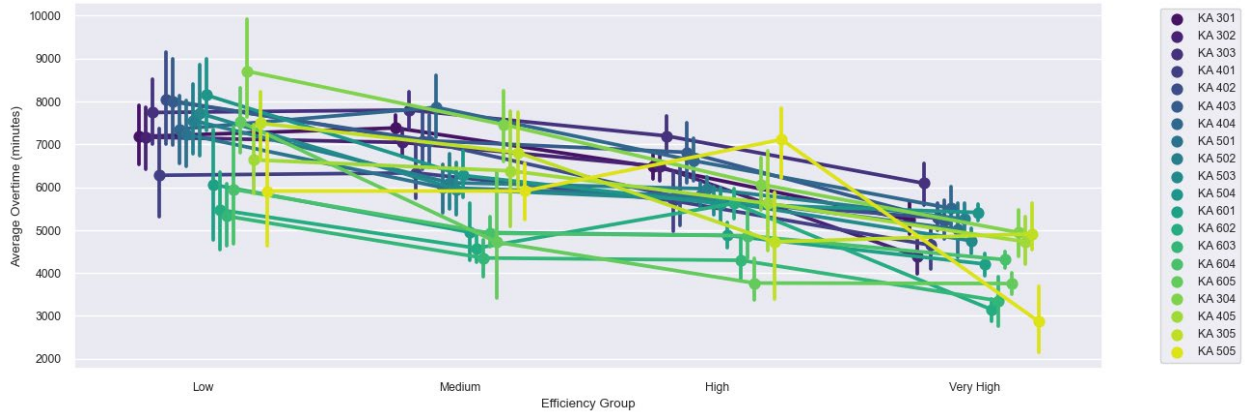


Figure 4. Interaction Between Efficiency Groups and Overtime by Production Line

observed in stable lines. Such volatility demands immediate investigation through time-motion studies and equipment audits to identify and resolve the underlying systemic issues.

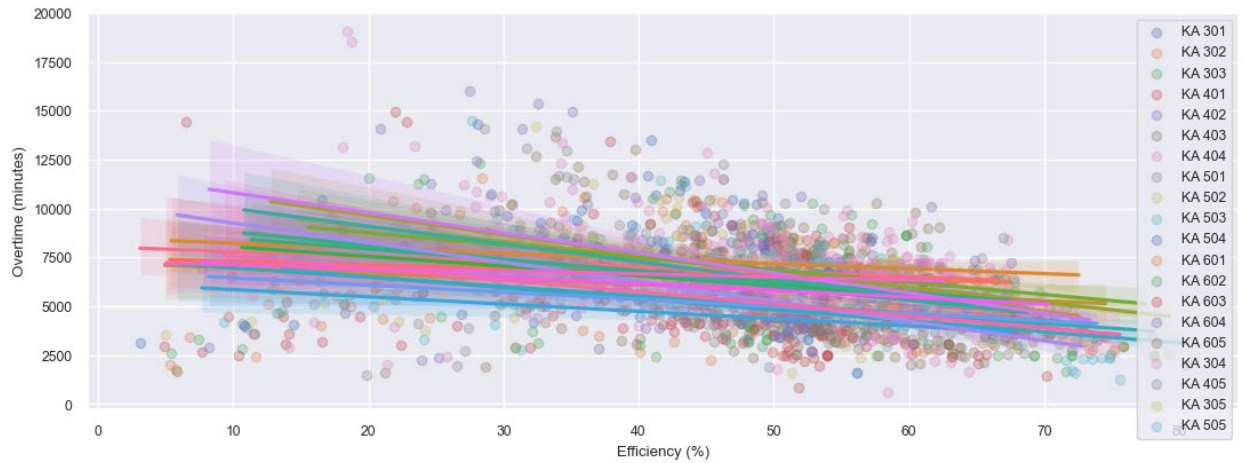


Figure 5. Marginal Effects: Efficiency vs Overtime by Production Line

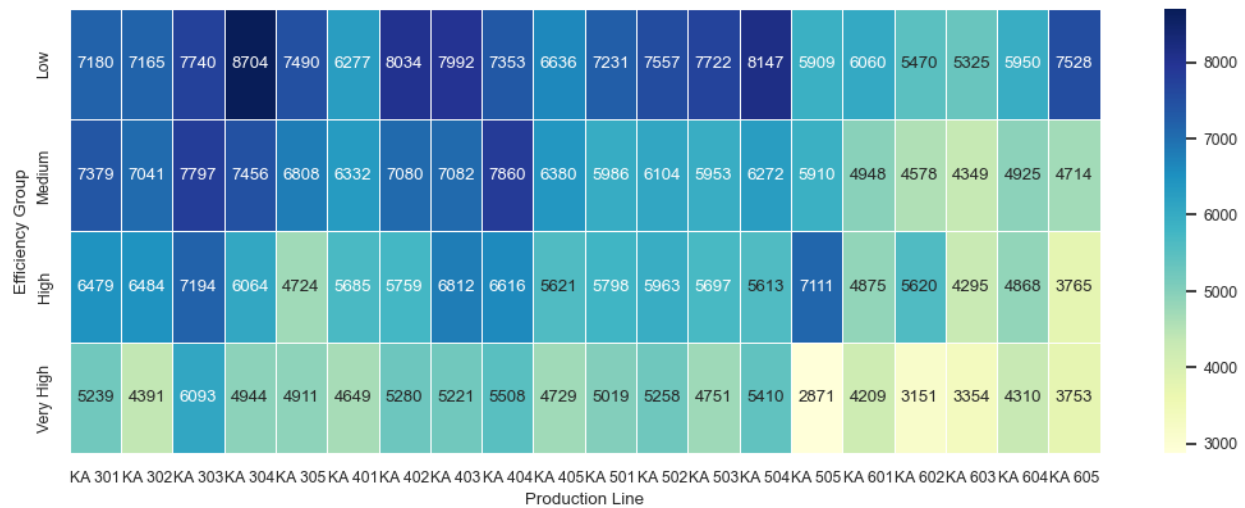


Figure 6. Average Overtime by Efficiency Group and Production Line

5.5. Comprehensive Analysis of SMV-Overtime Interaction Effects

The boxplot (Figure 7) analysis reveals three characteristic overtime patterns across SMV groups: (1) lines with strong negative correlation show progressively lower medians and tighter interquartile ranges as SMV increases; (2) non-responsive lines maintain consistent median values and compact quartile ranges regardless of SMV level; and (3) volatile lines exhibit irregular median fluctuations with wide, skewed distributions. While most production lines demonstrate decreasing variability in higher SMV groups, the presence of all three patterns in the same operational environment confirms fundamental differences in how individual lines respond to SMV adjustments. The visualization highlights that overtime distributions cannot be standardized across production lines, as each displays unique dispersion characteristics and sensitivity to SMV changes. The analysis of the interaction effect between SMV (Standard Minute Value) and overtime across production lines was conducted using both statistical tests and visualizations. The model comparison indicates that the interaction between SMV and production lines is statistically significant, with an F-statistic of 14.22 and a p-value of 1.68e-79, confirming the significance of the interaction effect. The OLS regression model further supports this, showing a significant relationship between SMV and overtime for specific production lines. For instance, KA 304 shows a strong negative relationship between SMV and overtime, with a slope of -75.40 ($p < 0.001$) and an R-squared value of 0.35, suggesting that for this line, higher SMV leads to a reduction in overtime. In contrast, KA 303 shows no significant relationship ($p = 0.7101$), and KA 505 displays substantial variability in overtime across SMV levels, with a slope of 614.24 but a non-significant p-value (0.0935). Additionally, the Average Overtime figure (Figure 8) illustrates how overtime varies with SMV across production lines. The low and medium SMV group shows the highest overtime across most lines, with KA 303 having the highest

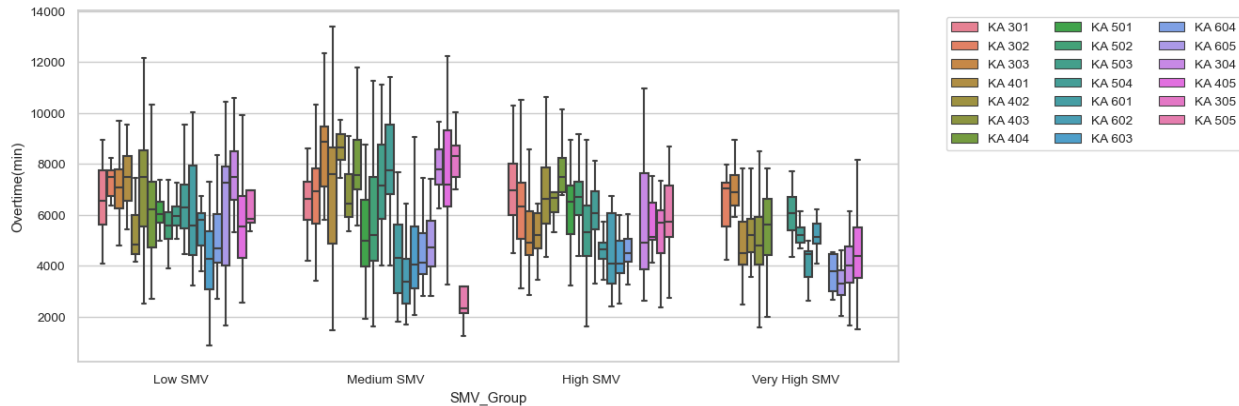


Figure 7. Overtime distribution by SMV group (all lines)

overtime (8861). Similarly, KA 302, KA 304, KA 401, KA 402, KA 404, KA 503, KA 504, KA 605 show the comparatively higher overtime in in the medium and low SMV in production line. On the other hand, KA 304, KA 401, KA 402, KA 403, KA 604, KA 605 etc. face lower overtime in the very high and high SMV group (see Figure 8). However, some lines (KA 301, KA 305, KA 501, KA 503) show the volatility condition and the overtime fluctuate without maintaining the SMV effect like others. Finally, Figure 9, indicates that, SMV increases, overtime generally

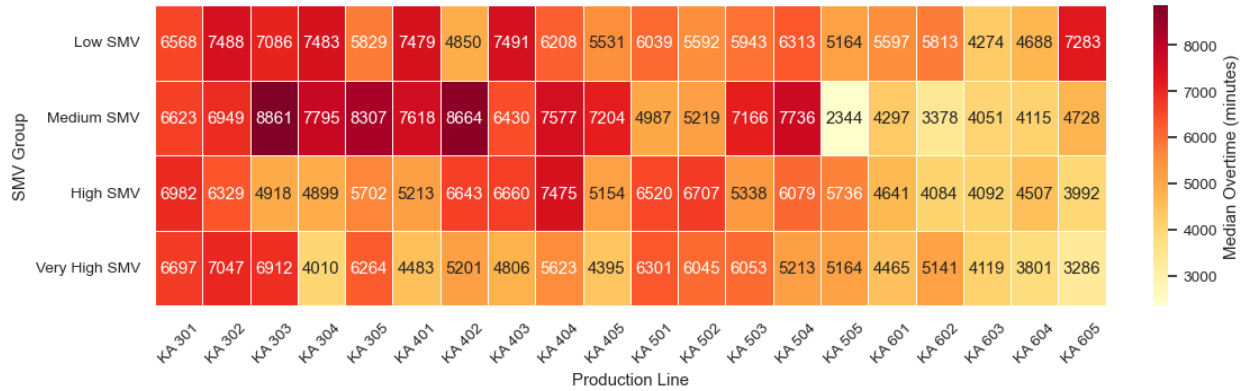


Figure 8. Median Overtime by SMV Group and Production Line

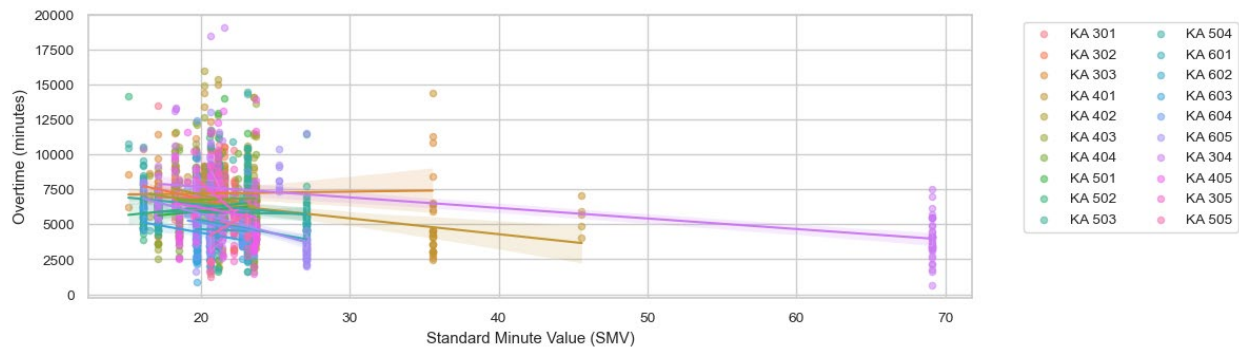


Figure 9. Marginal effects of SMV on overtime by production line

decreases, particularly in the High SMV and Very High SMV groups. The results suggest that SMV has a significant impact on overtime, but this effect also varies across different production lines. Some lines support the idea that optimizing SMV can lead to better productivity and reduced overtime, likely due to better process management or efficiency improvements. However, some others show no significant relationship, suggesting that other factors, beyond SMV, may influence overtime in this production line. The volatility (KA 301, KA 305, KA 501, KA 503), further highlights that higher SMV does not always guarantee reduced overtime, pointing to possible operational inefficiencies or inconsistencies in production. The Average Overtime table clearly illustrates the trend where lines with higher SMV generally experience lower overtime, but exceptions irregularly fluctuate line show that SMV is not the sole determinant of overtime (see Figure 9). This variability indicates that while improving SMV can reduce overtime, it is critical to consider other factors such as line-specific inefficiencies, staffing, or machine performance to fully optimize overtime and productivity (Boddapati et al., 2025; Reddy et al., 2018).

5.6. Comprehensive Analysis of SMV-Efficiency Interaction Effects

The ANOVA results for the interaction between SMV and Efficiency show that the interaction effect is significant, with an F-statistic of 12.42 and a p-value of 2.99e-37. The line factor shows p-value is 7.21e-18, that indicates that the relationship between SMV and efficiency varies significantly across different production lines. The box plot (Figure 11) reveals a clear inverse relationship between SMV and efficiency across production lines. Efficiency is highest in the low SMV tertile and declines significantly in the high SMV group, corroborating the line-specific negative coefficients from the ANOVA.

However, the wider Interquartile Range (IQR) in high SMV suggests variability, possibly due to divergent responses like KA 305's positive slope (see Figure 10).

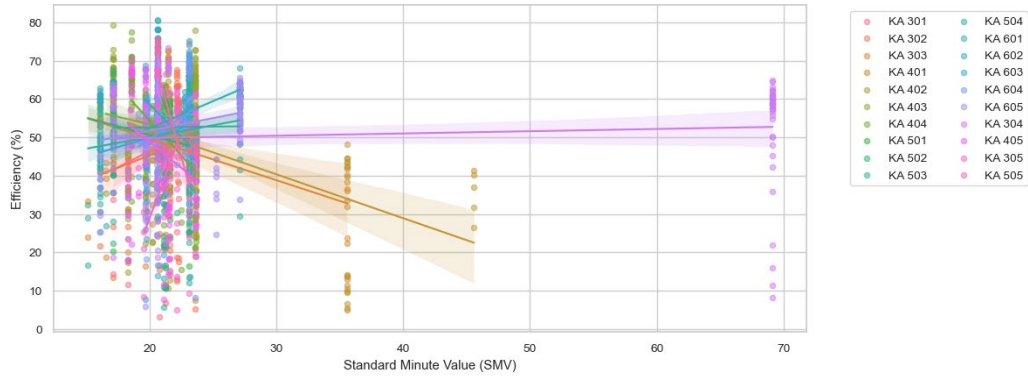


Figure 10. Marginal Effects of SMV on Efficiency by Production Line.

Interpreting the results, the data highlights significant variations in efficiency across the SMV turtles for different lines. Almost half of the total lines (KA 303, KA 401, KA 402, KA 404, KA 503, KA 602, KA 605 etc.) indicate that, when SMV group value decrease from high to low than the line efficiency increase (see Figure 12). The negative

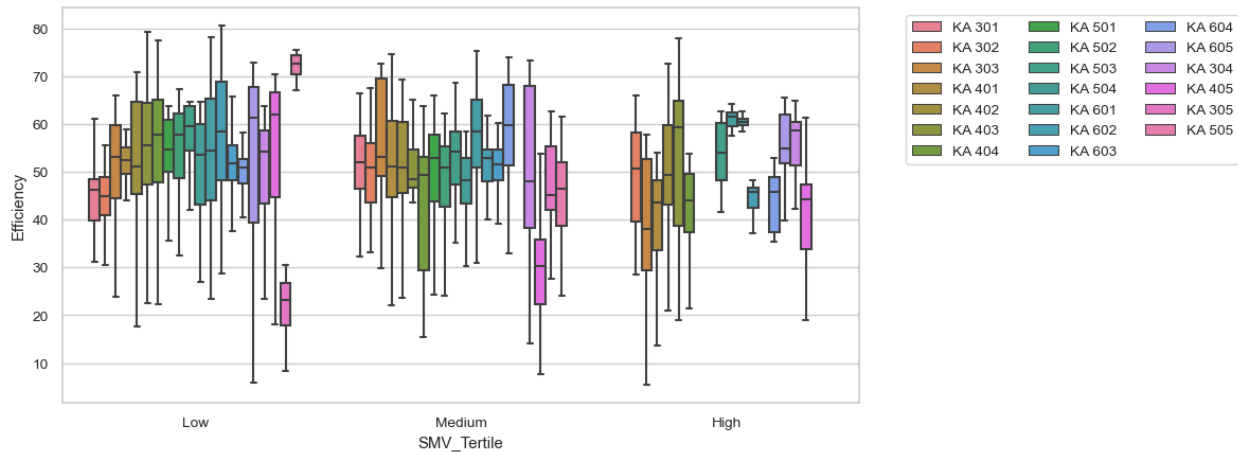


Figure 11. Efficiency Distribution by SMV Group and Lines

correlation suggests that, when SMV is low, the worker needs overtime and as a result their production time increase. As production time increase then the efficiency also increases. Others lines shows an irregular characteristic that, their efficiency trend slightly increase when SMV value increase but immediately it changes its trend without reason (see

Figure 10). These erratic conditions indicate that, SMV and efficiency have not rigorously related to each other's. It's depends on line specific character though most of the time they show a negative correlation in this specific factory.

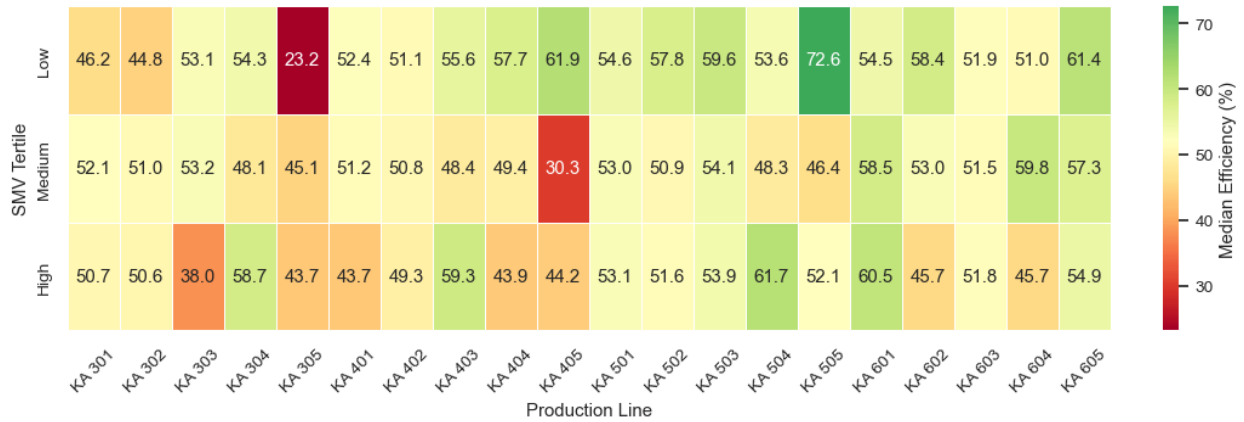


Figure 12. Median Efficiency by SMV Group and Production Line

KA 505 shows a significant decrease in efficiency with higher SMV, as efficiency drops from 72.6 in the Low SMV tertile to 46.4 in the High SMV, indicating a negative relationship. But several lines show minimal changes in efficiency across SMV tertiles, suggesting no substantial interaction effects. The patterns observed here reflect the previously analyzed interaction effects, with certain lines exhibiting stronger sensitivity to SMV changes, while others remain relatively unaffected. These findings reinforce the conclusion that the relationship between SMV and efficiency varies across lines, highlighting the need for line-specific analyses in efficiency optimization strategies.

6. Conclusion

The research focused on analyzing the multivariate relationships between Efficiency, Overtime, and SMV (Standard Minute Value) across various production lines at X Fashions Limited. The findings from six months of continuous data collection reveal complex patterns that differ across production lines. Efficiency and Overtime generally showed an inverse relationship, with higher efficiency linked to reduced overtime in several lines (see Figure 13). However, this relationship was inconsistent, with some lines exhibiting weak or no correlation, indicating that other factors, such as workflow and resource management, play a significant role in shaping overtime. Similarly, while a negative correlation between SMV and Overtime was evident in most lines, suggesting that higher SMV leads to reduced overtime, some lines displayed erratic patterns, underlining the influence of line-specific operational factors.

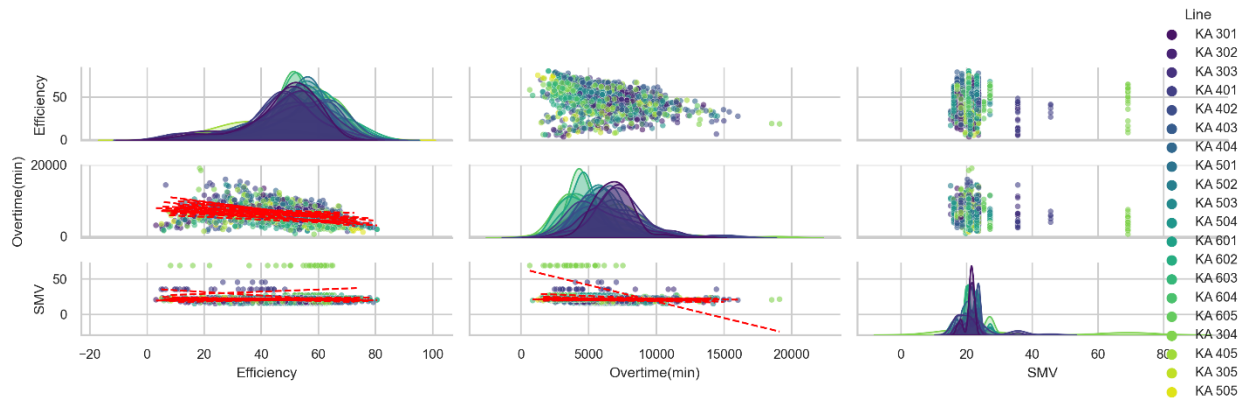


Figure 13. Multivariate Analysis: Efficiency, Overtime and SMV Relationships

Additionally, the analysis of Efficiency vs. SMV indicated that the relationship between these two variables varied across lines, with some showing weak positive or negative correlations, while others exhibited no clear pattern. The interaction between SMV and Efficiency was also significant, with lower SMV generally leading to higher efficiency in several production lines. However, some lines demonstrated inconsistent responses, further emphasizing the

importance of line-specific characteristics in determining efficiency outcomes. Overall, the variability in these relationships highlights the complexity of the production process, where factors like workflow, staffing, and line-specific dynamics play crucial roles in determining overall performance and should consider the unique operational dynamics at X Fashions Limited.

Managers should immediately prioritize root-cause analysis and stabilization of volatile lines like KA 305 and KA 505, where erratic efficiency-overtime relationships indicate severe operational disruptions. For consistently underperforming lines, practices from top performers like KA 601 and KA 602 should be standardized and adopted. Furthermore, SMV should be dynamically adjusted at the line level, as its impact on overtime and efficiency is highly variable, making real-time monitoring systems a critical investment for optimizing productivity and reducing costly overtime. The study emphasizes the necessity of addressing operational inefficiencies, such as inconsistent staffing and machine failures, to stabilize overtime patterns across production lines. Finally, these all insight can help managers allocate resources effectively, enhance workforce management, and ultimately improve overall factory productivity. Further research should investigate the root causes of volatility in unstable production lines and explore the integration of predictive analytics for real-time SMV and efficiency adjustments.

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