Minimization of Yarn Breakage Rate in Looming Process Using Parameter Optimization Techniques

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Abstract

In the weaving process, especially in the loom shed process, yarn breakage is frequently found to be a critical problem since it results machine downtime. This study aims to develop an optimal set of process parameter values by taking speed, air pressure, warp tension, backrest height, and relative humidity. Signal to noise ratio, optimal parameter combination, and ANOVA are determined using a Taguchi designed experiment. All parameters are found significant and the yarn breakage rate is reduced from 87 to 32 shift. Possible optimal regions and a predictable regression model is built using the response surface method. The regions are found capable by reducing the breakage rate to less than 32 per shift. Moreover, a genetic algorithm is employed using Matlab2014a so that the lowest possible yarn breakage rate is recorded, for which a model is identified using best-fit regression analysis. It can, therefore, reduce the yarn breakage rate from 87 to 8 per shift. Thus, this finding is determined to be significant for various textile weaving industries.

Keywords: Genetic algorithm, looming parameters, response surface method, Taguchi designed experiment, yarn breakage.

1. Introduction

Manufacturing industries play a crucial role in economic growth, especially for developing countries. Ethiopia is one of the few African developing countries that has experienced rapid growth in the manufacturing industries, reports from Tekeba E., (2018) and central statistics agency (2000) survey. From the available manufacturing industries, the textile sector contributed a large proportion as Embassy of Ethiopian Economy and business, (2008) reported.

Therefore, assuring the capacity of textile products, on behalf of economic growth, needs individual effort. Though each textile processing department has its own role for achieving the desired capacity, it is mostly determined by the weaving process. Not only this, but enough academic studies also hadn't been conducted in the weaving process (K. Khurana, 2018). Some factors limit the weavability or operability of loom to achieve the desired fabric quantity. Yarn breakage, availability of spare parts, inspection time, electric power cut, article and beam change, and operator absenteeism are the identified factors while this study was conducted. Similarly, the loom downtime has also challenged the other weaving industries. Hence, numerous scholars are attempted to minimize the frequency of loom-machine downtime.

For instance, some recent and related studies are assessed. The assessment shows that numbers of scholars, who have invested their potential, are increased to reduce loom downtime. Table 1 summarizes those selected studies in regarding to the objective of the study. The potential process and significant parameters, and also achieved improvements are considered to develop good benchmark. However, each study didn't present the effect of possible loom process parameters together and their interaction or cross-product on yarn breakage rate. For instance, Tsehaye D. et al., (2018) attempted to reduce the loom downtime by considering some factors using failure mode effect analysis (FMIE) but the entire process parameters were not studied well. Hence; in this study, the loom process parameters are selected and experiment is conducted.

Taguchi designed experiment, response surface method (RSM) and genetic algorithm (GA) are employed step by step to find out the best optimal loom process parameter values, which made the yarn breakage rate minimum. Taguchi designed experiment, developed by Genichi Taguchi in the 1980s, makes it easy and the number of experiments become minimum using an orthogonal array (OA). After conducting the OA operation, signal to noise (S/N) ratios are determined because robust parameter design can be built (Tung Hsu et al., 2007; D. Montgomery, 2009). Response surface method (RSM), developed by Box and Wilson in 1950, is an empirical statistical technique used in multiple regression analyses. The possible solution regions are identified, which are capable to reduce the frequency of yarn break (K. Vimalashanmugam and T. Viruthagiri, 2012; D. Montgomery, 2009). Genetic algorithm (GA), developed by John Holland in 1971, is also powerful and general-purpose tool used to search, the optimal parameter value as Tung-Hsu et al., (2007), M. Zheng et al., (2004) and C. Nwobi-Okoye et al., (2019) presented its application in the studies. Minitab statistical software tool are used to analyze Taguchi designed experiment and response surface method techniques whereas Matlab2014a tool is also used to perform the genetic algorithm optimization technique.

Table 1: The table depicted the selected journal articles with process parameters, significant parameter and improvements taken.

No.	Objective	Considered Potential Parameters	Significant Parameters	Improvements and some constants	References
1	Minimizing warp breakage	Relative humidity (RH%) only	Relative humidity (RH%)	Breakage rate reduced to 10/day at RH of 84% - 85%	Patil et al. (2017)
2		Warp tension	Warp tension	Optimal tension 20 cN and breakage rate reduced by 13%	Gloy et al. (2015)
3	Reduce machine down time	Warp tension and backrest height	Warp tension	Tension reduced from 132.04 cN to 106.32 cN and 0 warp stops per 100,000 picks	Yves-Simon et al. (2017)
4		Eight factors including speed	Loom speed	Downtime reduced by 14.2%	Tsehaye et al. (2018)
5	Determine weavability limit (yarn breakage)	Warp tension and backrest height	Warp tension	Maximum is 16.7 tex weft density	Yildiray & Recep (2011)
6		Loom speed and warp tension	Warp tension	At speed 520 rpm to 560 rpm and warp tension cN 80, weft breakage reduced by 10	Nkiwane et al. (2012)
7	Improve weft insertion speed	Air pressure and dragging force	Air pressure	From 6.79to6.565 Pa the speed of weft insertion is good	S. Jayawardana et al. (2017)
8	Control weft breakage	Air pressure	Air pressure supply	From 4.20 to 4.80 bar efficiency is improved by 5.5 %	Tushar (2016)
9	Modeling air consumption	Air pressure and warp tension	Air pressure supply	Improved by 0.0299(m^3/s)	R. Kumar et al. (2016)
10	Reduce weaving process setup time	Warp tension, speed and warp stop motion	Warp tension and pressure	Warp tension 1.27cN and pressure 134.23m^2/hiN, set up time reduced by 75%	M.Saggiomo et al. (2016)
11	Control quality of woven fabric	Warp tension	Warp tension	From 38 to 39 cN warp tension	SYED et al. (2013)
12	Examine weavability of fabrics	Warp tension and speed	Warp tension and speed	5 cN/tex to 13 cN/tex	A. Kim (2018)
13	Optimal loom setting	Warp tension only	Warp tension	132.04 cN to 106.32 cN, reduced by 0.3kN breaks	T. Gries et al. (2015)

1.1. Case Study Description

Looming is the process where textile fabric is made by using loom shed machines. In this division, yarn breakage was found the most critical problem that resulted in frequent loom downtime with a loss of 55.5% of the production time in 24hr. Being the study is experiment oriented, some requirements are considered. These include machine model: Omniplus800 air jet (picanol), material is cotton, fabric width 180 cm, yarn count Ne 20, yarn tenacity 6.86 cN/tex to 15.44 cN/tex, pick density 24 and room temperature 20^{o}c to 24^{o}c.

2. Methodology and Experimentation

Data are collected by direct observation and recording, besides discussion with operators. Three phases are employed in the study to achieve the lowest possible yarn breakage rate. Phase I emphasis Taguchi designed experiment; phase II is concerned on the response surface method (RSM) and in phase III genetic algorithm optimization technique is applied. Each phase is elaborated in the experimentation process. Before conducting the Taguchi designed experiment, facts are taken while the loom machines were working. These facts were used as a benchmark so that good experimentation is conducted. This is due to the unavailability of some standards in the existed working room.

2.1. Taguchi Design of Experiment (Phase I)

Step1: Identification of Failure Causes or Modes
Five major parameters are identified and the analysis is shown below using cause and effect diagram. The parameters are loom machine speed, air pressure, warp tension, backrest height, and relative humidity. From the analysis, too high and too low depicts that the parameter value sometime increases or decrease while the loom operators feed setting values.

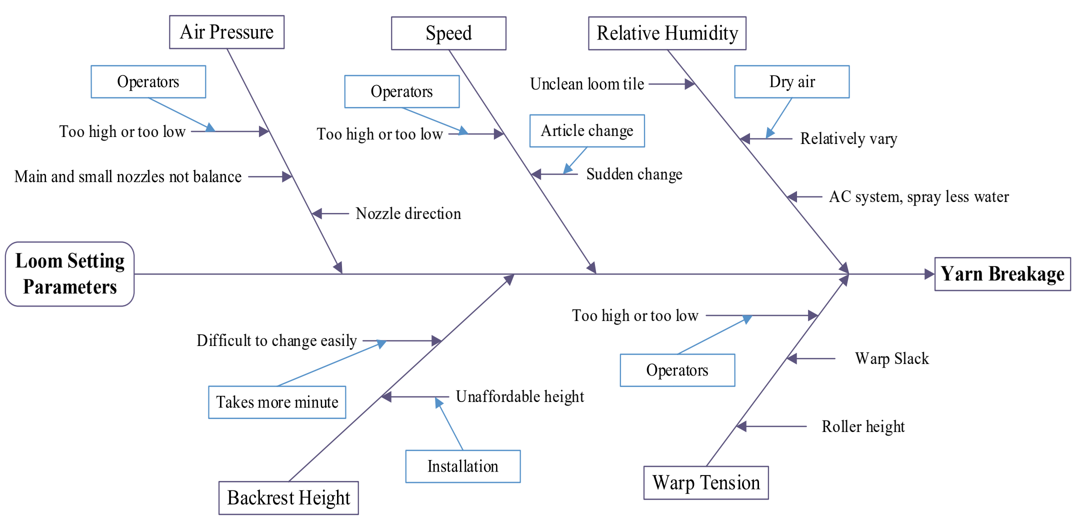

Figure1: Cause and Effect Analysis of loom process parameter for yarn breakage

Step 2: Identify the Noise Factors, Testing Conditions, and Quality Characteristics
Besides to machine vibration and operator's commitment, the strength of yarn has been tested using the *Tensorapid4* machine to identify the quality characteristics. It is found that the yarn strength was in the interval of 9.05 cN/tex to 15.44 cN/tex for sized and 6.87 cN/tex to 12.07 cN/tex for unsized. Hence, the parameter value out of the interval is determined as noise factor because it violates robust design.
Step 3: Identify the Objective Function to be Optimized
The objective of the study is developing optimal process parameter values to improve the production capacity of woven fabric. Therefore, minimize the yarn breakage rate is the objective function.

Step 4: Identify the Control Factors/Parameters and their Levels
To determine the control parameters and levels, scientific investigations, world-class standards and working culture of the case study are considered. Out of the 30 loom machines, 15 machines are taken randomly to collect preliminary facts. The fact showed that an average of 11 yarn breaks occurred in an hr. Of course, the loom setting values were varying while the fact was collected, see table 2 for setting parameter values. Then, the control parameters are defined as listed in Step1 and five levels are taken and the experiment is designed by L_{25} (or 5^5) type. The parameters and their potential location, in the looming system, are presented in figure 2.

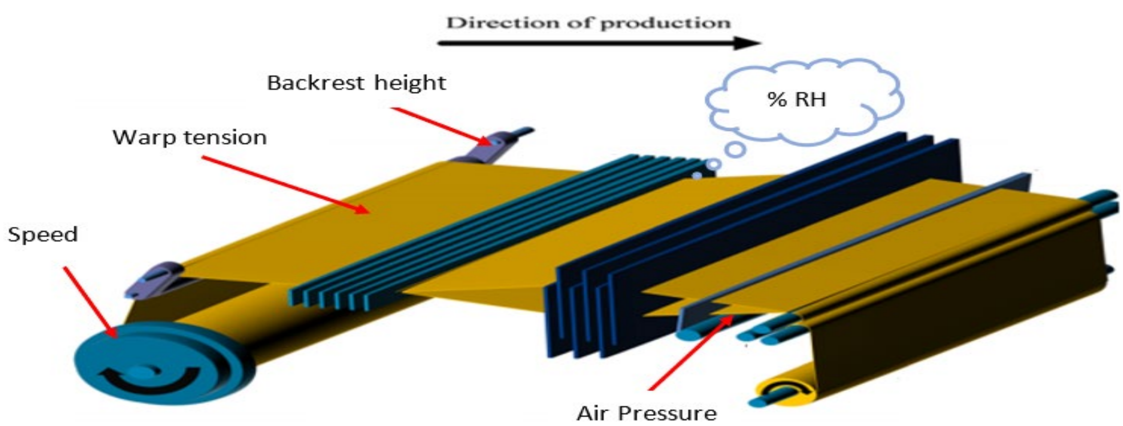

Figure 2: Schematic diagram of looming system that elaborates selected, but machine related, parameters indicated by arrows (Source: F. Cloppenburg, Y-S Gloy and T. Gries (2015))

Step 5: Select the Orthogonal Array Matrix Experiment
The combination of parameter values is left because a reader can construct the L_{25} OA matrix using SPSS or Minitab easily. The following table shows the orthogonal array (OA) of selected parameters with determined levels.

Table 2: Designed Values of Control Parameters with their Levels

	Levels				
Parameters	1	2	3	4	5
Speed (rpm)	445	465	485	505	525
Pressure (bar)	0.5	1.1	1.7	2.3	2.9
Warp tension (cN)	0.9	1.05	1.20	1.35	1.50
Backrest height (cm)	3	4	5	6	7
Relative humidity (%RH)	40 to 44	44 to 48	48 to 52	52 to 56	56 to 60

Step 6: Conduct the Orthogonal Array (OA)-Oriented Matrix Experiment
The orthogonal array (OA) is constructed using Minitab18. The OA consists of L_{25} parameter combination is, three trial experiments are conducted and the result is expressed by calculating the average of square sum. The result is defined in terms of mean breakage rate (MBR) per hr. since S/N ratio equation needs the mean of square sum value as defined in eqn. For illustration, MBR in run 1 can be calculated as:

$$MBR = \frac{1}{n}\sum_{i=1}^{n}(Ti^2) \qquad \text{eqn. 1}$$

Where:

T - defines experiments

i - defines experiments trials

n - total number of experiments trials

$$MBR = \frac{1}{3}\sum(10^2 + 13^2 + 13^2)$$

MBR = 146.00

The MBR results are then fed into Minitab18 software to develop an optimal set of loom process parameter values. Table 3 presents both the experiment run and its trial results in column for 25 experiments.

Table 3: Experiment Run and its Trial Results, Defined by MBR for L_{25} Taguchi Designed Experiment

	Run								
Trials	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
T1	10	13	10	8	8	11	6	12	10
T2	13	10	12	7	5	13	5	13	13
T3	13	13	11	9	8	9	4	14	13
MBR	146.00	146.00	121.67	64.67	51.00	123.67	25.67	169.67	146.00

	Run								
Trials	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
T1	9	10	10	11	7	10	11	11	9
T2	10	12	8	9	7	12	9	10	7
T3	8	11	9	10	7	11	10	12	11
MBR	81.67	121.67	81.67	100.67	49.00	121.67	100.67	121.67	83.67

	Run						
Trials	*19*	*20*	*21*	*22*	*23*	*24*	*25*
T1	12	9	9	11	15	16	15
T2	10	11	9	10	12	17	14
T3	11	10	9	9	15	15	16
MBR	121.67	100.67	81.00	100.67	198.00	256.67	225.67

Step 7: Data Analysis, Predict Optimum Levels and Significances Measurement
The S/N ratio value, in decibel (dB), at different levels of the parameter is shown in figure 3. The Taguchi S/N ratio characteristic for this objective function is taken as *"the-smaller-the-batter"* because minimum yarn breakage rate is required. The smaller the better function is expressed as:

$$S/N = -10\log{(MBR)^2} \qquad \text{eqn. 2}$$

Where:
S/N is signal to noise ratio

The-smaller-the-batter doesn't mean taking smaller signal values rather larger values. The smaller the better states that taking the smaller in the main effect plot for means can dominate the noise factors.
The effect of S/N ratio for each looming process parameter is calculated at different levels since the experiment is orthogonal (Tung Hsu et al., 2007; B. Shaik et al., 2019). All S/N ratio are found negative as shown in the left side of figure 3. Therefore, developing a set of high signal parameter values dominate the noise factor to develop the lowest possible yarn breakage rate. Either taking the set of larger values from

main effect plot for S/N ratios or taking the set of smaller values from main effect plot for means gives same data. From the figure, it can be determined that $S_{485}P_{1.1}T_{0.9}H_6R_{58}$ are the predicted optimal values.

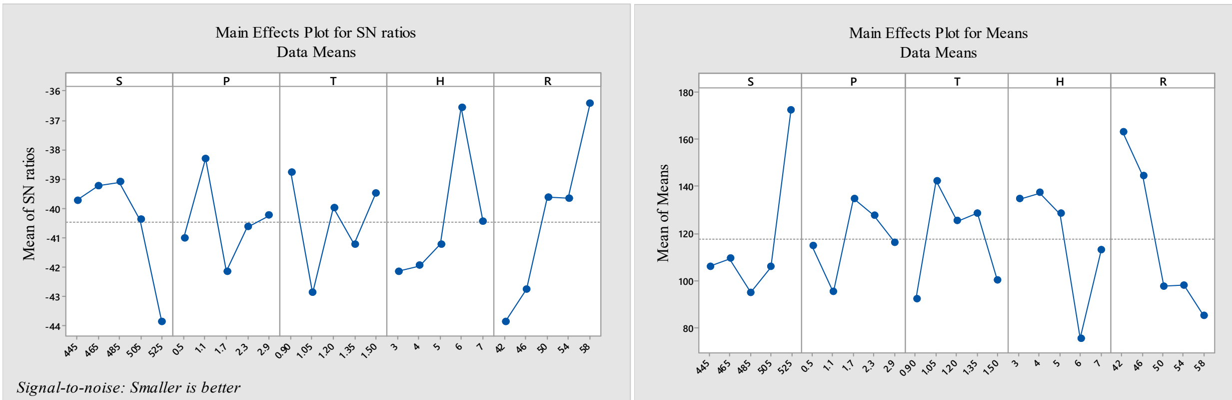

Figure 3: Plot of S/N ratio for yarn breakage, the high pick points depict the high signal value that are capable to dominate the noises

Step 8: Conduct the Confirmation Test

After finding the optimal set of input parameter values, a confirmation test is conducted to assure the investigated results. The rate of yarn breakage is lowered to 4 per hr. Not only this, but the significance measurement of each parameter is also taken into account. For measurement, analysis of variance (ANOVA) is employed, as shown below.

Table 4: ANOVA results for yarn breakage rate, a parameter with p-value less than 0.05 is taken as significant

Parameter	DF	SS	MS	F-Value	P-Value	Status	Contribution of SS
S	4	19325.8	4831.5	34.25	0.002		27.87%
P	4	4547.2	1136.8	8.06	0.034		6.56%
T	4	8673.3	2168.3	15.37	0.011	*	12.50%
H	4	12947.2	3236.8	22.94	0.005		18.67%
R	4	23290	5822.5	41.27	0.002		33.58%
Error	4	564.3	141.1				0.81%
Total	24	69347.8					100%

'*' all parameters are significant, not only for "T"

One drawback of Taguchi designed experiment is that the input parameter values are not dynamic after its experimental results. This implies that the change of one variable does not make the Taguchi designed experiment robust. Therefore, to make the looming system dynamic, developing a predictable regression model and possible optimal working limits using RSM is found as essential doing. For doing this, RSM followed the following steps.

2.2. Response Surface Method (Phase II)

Step 1: Designing and Conducting a Series of Experiments

The Taguchi designed experiment enabled to present a series of tests and results are investigated. Control parameters are taken as an independent variable and breakage rate as a response variable.

Step 2: Developing Mathematical Models with the Best Fittings
This step presents a sensitivity analysis of control parameters to make a predictable regression model for yarn breakage. Different models were formulated, but the best fit with the highest correlation coefficient (R^2) is selected as represented by breakage rate (BR) below. In regression analysis it is obvious to have a correlation between the response and predictor(s), but having correlation among predictors is something undesired (Jamal I. Daoud, 2017). The developed regression model consists of multiple parameters that needs multicollinearity test.
Hence, the study conducted multicollinearity test using SPSS V.20 software. The result shows that variance inflation factors (VIF) is less than 5 and the tolerance value is also greater 0.1. This depicts the correlation among the independent parameter is too poor so that the model is meaningful.

Table 5: Variance Inflation Factors (VIF) Values, Coefficients of Models is Defined in Eqn. 3

Model parameters		S	P	T	H	R
Collinearity Statistics	Tolerance	0.910	0.773	0.881	0.881	0.773
	VIF	1.099	1.294	1.135	1.135	1.294

The following equation shows the best-fit regression model of the selected parameters.

$$BR = -75393 + 458S + 4676P + 6781T + 639H - 114R - 0.945S^2 + 129.7P^2 - 5028T^2 - 103.8H^2 + 1.19R^2 - 20.7SP - 1.36ST - 0.288SH + 0.1177SR + 3.20PH - 0.96PR - 3.41TR + 0.000643S^3 - 24.46P^3 + 1394T^3 + 6.74H^3 - 0.0083R^3 + 0.0220S^2P \quad \text{(eqn. 3)}$$

The regression model is adequate because the difference numerical value between $R^2 = 99.85\%$ and R^2 adj. = 96.48% is 3.37% as M. Mourabet et al., (2017) justified in previous study. Not only this but the cross-product effect of independent parameter on the yarn breakage is also checked.
The cross-product result is presented using RSM since it is capable to show the possible *regions*, where the yarn breakage rate is less 7 per hr or square root of 50.
The BR result from 50 to 200, at the right top corner of figure 4, presents square value of encoded data. For instance, the figure presents the lowest possible yarn breakage rate regions. Here, region depicts the plot or surface limit that the cross-product possess minimum yarn breaks. From the two cross-product parameters, the first represents horizontal whereas the second represents the vertical line.

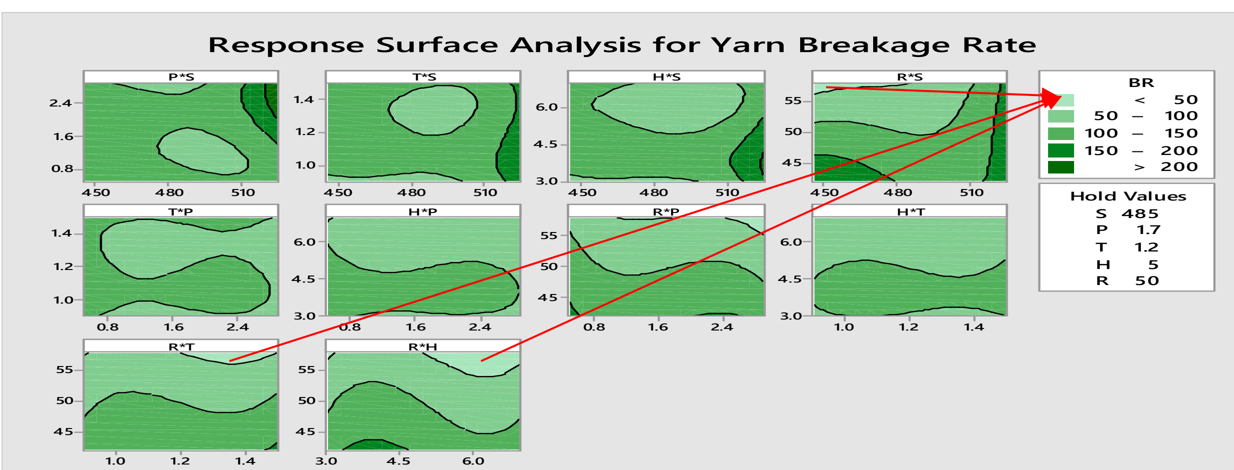

Figure 4: Possible Regions for Optimal Parameter Values of Looming Process, the Pale Green Region that is Represented by the Line Depicts Smallest Yarn Breakage Rate

As shown in the figure, individual plots are a result of two variables that signifies their interaction on yarn breakage. Even though the two-parameter interaction was not significant, it is attempted to see the effect of the all interaction on the response variable using a genetic algorithm (GA) optimization technique.

2.3. Genetic algorithm (Phase III)

For conducting GA optimization, designed parameters and levels are assigned as chromosomes and genes respectively to perform the operations called *selection*, *crossover*, and *mutation* using the Matlab2014a statistical tool. The following figure, modeled by visio16, shows how the GA is performed. Two steps are used to perform the GA optimization technique.

Step 1: Assignment of control parameters as chromosome and levels gene
Loom speed (S), air pressure(P), warp tension(T), backrest height(H) and relative humidity(R) are assigned as chromosomes and each level under each control parameter is also assigned as a gene. The following figures present the assignment of the required parameter and its working approach.

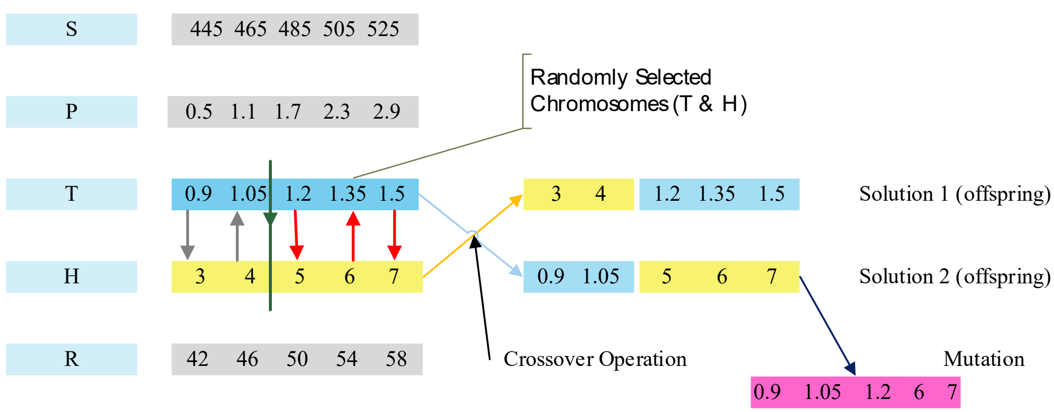

Figure 5: Working Principle of GA Optimization, Each Offspring Signifies the Possible Solutions

Step 2: Develop Objective Function to Measure the Fitness of an Individual Chromosome and possible solutions

Equation 3, the regression model, can be taken as an objective function. The smaller values of each level are categorized as lower bound, [445 0.5 0.9 3 42], and the larger values as upper bound [525 2.9 1.5 7 58]. The analysis, generated from GA, presents the lowest best breakage rate 0.5 near to 1 per hour and the worst breakage rate is 1.5 near to 2 per hour. The horizontal line depicts the number of possible generations (solutions) based on the designed stall function, and with default value 50 runs. The stall function is the score that the best fit value ceased iteration.

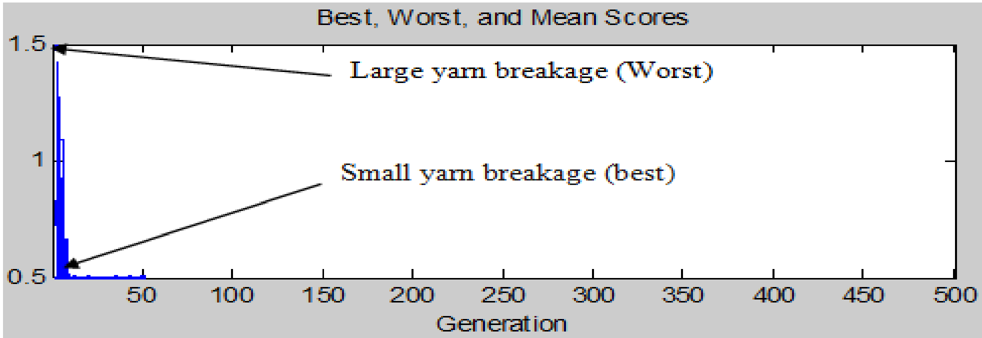

Figure 6: The best and worst yarn breakage rate, the result is not verified

3. Results Discussion

So far, it is discussed on the methods how yarn breakage is minimized; indeed, the objective of the study is not a comparison of optimization techniques rather an acquiring of the lowest yarn breakage rate. From the collected fact, the expected downtime caused by yarn breakage was 0.54hr per shift and 8.9m loss. Therefore, one yarn break can record 0.006hr downtime; divide 0.54hr per shift by 87 breaks per shift. In general, the findings are presented in the following table.

Table 5: Improvements gained in each optimization technique, the results are presented in terms of yarn breakage and woven fabrics

The Required Metrics (performed on a single machine)	The Result of Optimization Techniques		
	Taguchi DoE	*RSM Optimization*	*GA Optimization*
Number of yarn breaks per hr.	4	Less than 7	1
Expected downtime (hr.)	0.006*4 = 0.024	0.006*7= 0.042, but Less than 0.042	0.006*1 = 0.006
Reduced downtime (hr.)	0.0435	Less than 0.0435	0.0615
Expected unwoven fabric (m/hr.)	$\frac{8.9*0.024}{0.54} = 0.39$	$\frac{8.9*0.042}{0.54} = 0.69$, but Less than 0.39	$\frac{8.9*0.006}{0.54} = 0.099$
Existed unwoven fabric (m/hr.)	$\frac{8.9m}{8hr} = 1.1125$	$\frac{8.9m}{8hr} = 1.1125$	$\frac{8.9m}{8hr} = 1.1125$
Improved woven fabric (m/hr.), expected – existed unwoven fabric	0.72	Greater than 0.72	1.01

Conclusions

The objective of the study was to develop an optimal set of process parameter values of the weaving process, in looming division using Taguchi designed experiment, response surface method and genetic algorithm to investigate the lowest yarn breakage rate. It has been found that the rate of yarn breakage can be lowered when the response surface method and genetic algorithm are applied respectively than Taguchi designed experiment. But except Taguchi designed experiment, the latter two are not validated through confirmation test so that it has concluded for employing the confirmed one. This could be achieved when the yarn strength is in between 9.05 cN/tex to 15.44 cN/tex for sized and 6.87 cN/tex to 12.07 cN/tex for unsized. But results obtained from the response surface method and genetic algorithm hadn't been carried out for confirmation test. Hence, future researchers had better look through statistically analyzed results with real results to confirm it.

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Biography

Muluken Abebe is a young researcher, and vice dean of faculty of mechanical and industrial engineering. He earned B.Sc. in Industrial Engineering from Dar Institute of Technology, Bahir Dar University, Ethiopia; Masters in Production Engineering and Management from Dar Institute of Technology, Bahir Dar University, Ethiopia. He has participated in different conferences.