

THE ESTABLISHED SINGLE OBJECTIVE MODELS FOR OPTIMIZING THE COST OR SELECTED PERFORMANCE PROPERTIES OF TOWELS

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ABSTRACT

This study aimed to optimise the cost or selected performance properties (softness, hydrophilicity etc.) of towel fabrics. For this purpose, the developed mathematical equations based on physical and performance properties of a towel have been used as objective function and constraints in the designed models. With these models adopted, the physical properties such as pile height, warp and weft densities, being used in real production conditions, have been attempted to predict under the conditions that the performance properties selected might take the best values for given constraints.

Keywords: Towels, models, optimization, prediction, LINGO 8.0

1. Introduction

Similarly as in all textile products, in the towel fabric production, depending on the plant conditions and customer demands, it may be aimed that the cost or one performance properties (softness, hydrophilicity, breaking strengths) should have the best values. For this aim, the mathematical models can be established in the frame of the “Operation Research”.

Model can be defined as the group of expression that determines the relationships between the elements through the words or mathematical terms in order to examine the behaviours of a system under changing conditions, to control it and to make assumptions about the future. Except some special cases stemming from the problems handled, all the other models are composed of objective function and constraints. The objective function is defined as the mathematical expression of the parameter aiming the optimization in the model, whereas the mathematical expression of the limitations caused plant conditions, product properties etc. are called as constraint. Since the relationships between the variables of the problem that is handled in models are expressed in mathematical form, the understanding of the model and reaching the solution is generally easy even in the complicated cases. Aiming to realize a single purpose in models, this attempt is called “single objective models”, in the case of achieving multiple purposes simultaneously, these models are designated as “multi objective models”.

A research has been carried out by Sindel, Nouri-Baranger and Trompette on sensitivity analysis and optimization models used in defining the fabric structural parameters. In this investigation, the two methods mentioned above were compared for various samples. From the result of these comparisons, it was found that the optimization method gave more successful results than those of the other [1]. Gotlih, Lojen and Vohar aimed to optimize needle’s penetration speed into the fabric in sewing machines without decreasing the sewing speed with the nonlinear optimization model being created [2]. A model was developed to optimize the structural parameters of a fabric by Chen and Leaf in 2000, by using the software called Mechfam [3].

In mathematical models, generally, the maximization of the profit or the minimization of the cost is aimed. In commercial units or plants, it is generally expected that the products to be manufactured should have certain properties; besides the cost of these products being at a minimum level. In some cases, however, depending on the requirements set out by the plants

or customers, discarding the production cost, the minimization and/or maximization of one or more performance properties (softness, hydrophilicity and weft-warp breaking strengths) may be aimed. In order to reach this achievement, the physical properties or characteristics of the towel considered should be determined and it may be desired to predict the production cost of related towel produced with the properties defined. The solutions of these models are performed with LINGO 8.0 software and the obtained results are evaluated in the present study. With these models developed, from the solution reports of the models, it may be possible for the plant management to gain time and make desirable profit by preferring a suitable production mode.

2. The Results of Single Objective Optimization Models Established

2.1 Models

In this investigation, five theoretical models in which cost, softness, weft breaking strength, warp breaking strength and hydrophilicity being optimized (to be maximized or minimized) individually were established, providing that some selected properties have certain values within defined limits. These models have been designed with the same principle, with the exception of the objective function expressions being different depending on the related property to be optimized.

In these models developed, in optimizing weft and warp breaking strengths, it is expected that these properties should take the possible highest value (i.e. maximization). Besides this, for any towel, due to the principle of test method, the smaller the value of softness which is defined experimentally, the higher the softness degree of the corresponding towel will be. For this reason, in the models, the optimization of the softness means the minimization of the softness values (the amount of the load to be applied).

While defining the hydrophilicity level of the samples, "Sinking Test" was used. This test is based on measuring the time passed until the whole experimentation sample submerged wholly. In generally, decreasing the sinking time of samples increases the hydrophilicity degree and while optimizing hydrophilicity degree, the minimization of measured values (sinking times) for this parameter has been aimed.

In these established models, generally the definition of required physical parameters for the optimization of selected performance property is aimed and in order to calculate the cost of production, a parameter expressing the unit production cost (C) is also included into the models. This parameter is composed of the sum of raw-material cost (HM) and general production cost (GIG) per unit production (U). "Raw-material cost" is defined as total cost of the yarn required for the production of 1 square meter towel fabric and this expression includes pile and ground warp yarns and weft yarns in terry production. "General production costs" are, however, composed of amortizing cost ($Amort_m$), labor cost (I_m) and energy cost (E_m). Accordingly, the expression of the unit production cost (C) has been obtained and given as below [4, 5, 6].

$$C = HM + \frac{GIG}{U} = HM + \frac{(Amort_m + I_m + E_m)}{U} \quad (1)$$

Considering the unit conversions and evaluating the related parameters defined as above the equation 1 takes the form;

$$Z_{min} = \left[\frac{CS(100+k_z)}{4} \frac{ZC_F}{ZN*1,693} \frac{1}{1000} \right] + \left[\frac{25*CS*HY}{HN*1,693} \frac{HC_F}{1000} \right] + \left[\frac{AS(100+k_A)}{2} \frac{A_F}{AN*1,693} \frac{1}{1000} \right] + \frac{\left[\frac{TF}{Asüre*300*22,5} \right] + \left[\frac{IÜ/mak}{25*7,5} \right] + [(M+A+K)*EF]}{\frac{n*120*V*TE}{AS*100}} \quad (2)$$

The constant or variable parameters defined as in this cost expression (equation no 2) are demonstrated with their symbols in Table-1. In the table, as well as the symbols, the constant parameters with the assigned values can also be seen (i.e. the price of ground warp yarn has been taken as constant with 3 TL/kg). These values have been specified by taking into account the production conditions and the characteristics of the weaving loom used for sample towel fabrics production and they can easily be handled on the model as required. In the theoretical approach, in general, the physical properties of fabrics defined are taken as constant, whereas the prices needed in determining the cost equation and the working parameters of the loom used in production are taken as variables.

Table-1 The Constant and Variable Parameters Used in the Models

Constant Parameters	Symbols	Values	Variable Parameters	Symbols
The Price of Ground Warp Yarn	ZC _F	3 TL/Kg	Weft Density	AS
The Price of Pile Warp Yarn	HC _F	2 TL/Kg	Warp Density	CS
The Price of Weft Yarn	A _F	2 TL/Kg	Pile Warp Yarn Number	HN
Labor Cost	İÜ	400 TL	Weft Yarn Number	AN
The Price of the Loom	TF	90000 TL	Pile Height	HY
Loom's Amortization Time	Asüre	2 years	Ground Warp Crimp	KZ
Loom Productivity	V	%80	Weft Crimp	KA
Loom Speed	n	260 rpm		
Loom Motor Power	M	15 kW		
Energy Used for Lighting	A	0,8 kW		
Energy Used for Air Conditioning	K	2 kW		
The Price of Electricity	EF	0,190 TL/kWh		
Number of Machines Per Worker	mak	4 unit		
Loom Width	TE	3,6 m		
Ground Warp Yarn Number	ZN	Ne 10		

Objective Functions:

Table-2 illustrates the purposes of the models developed and the objective functions chosen suitable to these purposes. It can be seen from the table that the proposed two models are based on maximization while the rest of the models are designed with the aim of minimization.

Table-2 Objective Functions of the Designed Optimization Models

Model No	Model's Purposes	The Expressions of Objective Functions
1	Minimum Cost (C)	$\min = \left(\frac{CS}{4} \right) \cdot \left(\frac{100 + KZ}{ZN \cdot 1,693} \right) \cdot \left(\frac{ZCF}{1000} \right) + \left(\frac{25 \cdot CS \cdot HY}{HN \cdot 1,693} \right) \cdot \left(\frac{HCF}{1000} \right) + \left(\frac{AS}{2} \right) \cdot \left(\frac{100 + KA}{AN \cdot 1,693} \right) \cdot \left(\frac{AF}{1000} \right) + \left(\frac{TF}{Asüre \cdot 300 \cdot 22,5} \right) + \left(\frac{IU}{mak} \right) \cdot \left(\frac{25 \cdot 7,5}{(M+A+K) \cdot EF} \right) \cdot \left(\frac{n \cdot 120 \cdot V \cdot TE}{AS \cdot 100} \right)$
2	Minimum Softness (Y)	$\min = -0,530 \cdot ZN + 0,01856 \cdot G - 0,256 \cdot HY$
3	Maximum Weft Breaking Strength (Akop)	$\max = 24,307 \cdot AS - 30,569 \cdot AN$
4	Maximum Warp Breaking Strength (Ckop)	$\max = 17,246 \cdot ZN + 3,752 \cdot CS$
5	Minimum Hydrophility (H)	$\min = -6,957 \cdot HN - 0,451 \cdot G + 6,954 \cdot AS + 3,259 \cdot CS$

The objective function expressions coinciding with the models under investigation have been obtained so as to contain the performance features as mathematical relations developed by the serious statistical analysis applied. These equations have been developed by applying regression analysis adopted using SPSS package program. The data for package program, such as weight, pile height, densities, yarn counts, crimps, softness, hydrophility and breaking

strength values, were determined experimentally with standard test methods. Before applying the regression analysis, for the test purposes, in another word whether the required conditions for the models were suitable for applying regression analysis or not, K-S test (the test of conformity to normal distribution) and Runs test (random test) were applied to the data considered and consequently histogram graphs for the data groups processed were formed. After these attempts the regression analysis has been applied by considering the related results from the statistical tests. In addition to these, the significance levels of the equations for the five models developed have also been tested by using correlation analysis technique. It has been seen that the correlation analysis gave the high significance levels for all equations.

Constraints:

The statistical study applied to form the equations belonging to performance properties selected as objective function, is also applied to obtain the equations expressing the physical properties mathematically. In the models, these mathematical expressions for physical and performance properties are used as constraints and limit values for these constraints are taken by evaluating the data commonly used in the industry and included in the literature. These limit values represent the highest and/or the lowest values of the related parameter while optimizing a selected property. The expressions used as constraint with their limit values are given in Table-3. From the table, it can also be observed that some equations concerning the properties to be optimized in the models have been selected as objective function, while the rest equations have been evaluated as constraint [6,7,8].

Table-3 Constraint Expressions in the Models

Variables	Constraints
Weight (G)	$380 < -25,476*HN + 10,407*ZN - 5,991*AN + 3,464*AS + 8,545*CS + 46,1*HY < 700$
Pile Height (HY)	$5 < -4,587 + 0,481*HN + 0,008783*G < 15$
Warp Density (CS)	$36 < 1,047*HN + 0,990*ZN + 0,688*AN + 0,02806*G < 52$
P. Warp Yarn Number (HN)	$8 < 16,398 - 0,264*AN - 0,0204*G - 0,233*AS + 0,283*CS + 1,11*HY < 20$
Weft Yarn Number (AN)	$9 < -0,371*HN + 1,054*ZN - 0,01377*G + 0,325*CS < 20$
Weft Crimp (KA)	$5 < -0,00817*G + 0,432*CS < 20$
G. Warp Crimp (KZ)	$5 < 0,386*AS + 0,748*ZN - 0,729*AN < 20$
Weft Density (AS)	$30 < 0,188568*G - 0,000337*G^2 + 2,122*10^{-7}*G^3 < 48$
Weft Breaking Strength (Akop)	$24,307*AS - 30,569*AN > 274$
Warp Breaking Strength (Ckop)	$17,246*ZN + 3,752*CS > 333$
Softness (Y)	$0,1 < -0,530*ZN + 0,01856*G - 0,256*HY < 6$
Hydrophilicity (H)	$2 < -6,957*HN - 0,451*G + 6,954*AS + 3,259*CS < 50$

In this theoretical study, in addition to the models being developed for optimizing four performance properties described above, a model with the objective of cost minimization has also been handled. In this new model, the whole equations prescribing the performance properties were considered as constraint, while the cost expression was used as objective function. The solution report of this model has been assessed along with the solution reports of the other models developed [6].

2.2 Solutions of the Models and Discussion

The models developed as described above have been solved by using LINGO 8.0 optimization software. The value belonging to the objective function (a value for the parameter being optimized) is denoted as the “best value” of which the performance property concerned or cost should take under the constraint defined. However, due to the construction of the towels, while trying to optimize one of the performance properties selected, the remaining performance properties and/or cost of production of the towels can be affected undesirably.

The physical and performance properties and cost values obtained with LINGO 8.0 software solutions for the models developed are given as in Table-4. From this table, it can easily be noted that, if only one parameter (cost or any performance property) is given priority (aimed to be maximized or minimized) and the other parameters are expected to take the values within the given limits (constraints), the models gave the best values defined above for the performance properties such as softness, weft and warp breaking strengths and hydrophilicity as 2.97 kgf, 637.62 N, 367.56 N and 35.41 sec. respectively and for the cost 1.702 TL.

Table-4 Solution Results of the Models

Model No	Objectives	Parameter Values												
		Input parameters*								Output parameters*				
		G	HY	AS	CS	AN	HN	KA	KZ	C	Y	Akop	Ckop	H
1	min (C)	566,33	8,57	37,24	50,58	10,12	17,03	17,22	14,47	1,702	3,01	595,95	362,26	50,00
2	min (Y)	561,28	8,38	37,19	49,35	9,00	16,72	16,73	15,27	1,705	2,97	628,96	357,62	50,00
3	max (Akop)	591,90	9,47	37,55	52,00	9,00	18,43	17,62	15,41	1,787	3,25	637,62	367,56	35,41
4	max (Ckop)	589,36	9,39	37,51	52,00	9,30	18,29	17,64	15,17	1,775	3,23	627,46	367,56	37,26
5	min (H)	591,90	9,47	37,55	52,00	9,00	18,43	17,62	15,41	1,787	3,25	637,62	367,56	35,41

* : Input parameters express the physical properties to be known in the plant before production whereas the output parameters express the performance properties of the product that will be obtained after production.

Additionally, when the solution reports of all established models are evaluated, under the condition that the aim of the model is changed and the constraints are remained as constant, weight values varied between 561.2-591.9 gr/m², pile height ranges from 8.3 to 9.4, weft and warp densities change within the range 37.1-37.5 weft/2cm and 49.3-52.0 warp/2cm respectively. In addition to this, weft and pile warp numbers range from Ne 9 to 10.1 and from Ne 16.7 to 18.4, weft and ground warp crimps varied between 16.7-17.6%, 14.4-15.4% respectively. Hence, it can be inferred that while the priorities of the objective for the models are changed and the limit values of the constraints remain constant, the values of the physical properties will take the values very close to each other (except HY and G).

From the table it can also be seen that the models gave the performance properties as; Akop values ranging from 595.95 to 637.62 N, Ckop values changing between 357.62-367.56 N, softness values being varied between 2.97-3.25 kgf and hydrophilicity values changing from 35.41 to 50 sec. From these results, it was shown that remarkable variations occurred in weft breaking strength and hydrophilicity values under the conditions that the objective of the model was changed while the related constraints remained as constant.

As it is seen from the same table, the lowest cost value to be reached has been obtained as 1.702 TL with the solution of the model 1 aimed only cost minimization. Similarly, it can be seen that the models denoted as 2, 3, 4 and 5 in which performance properties are taken as objective function individually, have also given the best value for the related performance property. Accordingly, as explained before, the values taken by the objective functions relating to these models are described as the best values of which the parameters Y, Akop, Ckop and H should take under the constraints defined. However, when the objective of the model was based on the cost minimization, certain deviations from the best values expected have been observed for these parameters mentioned above. In other words, when the production cost was the main aim in optimization procedure, a considerable deterioration in fabric performance properties was detected, as demonstrated in Table-5.

Table-5 Comparison of the results of cost minimization model and the best values

Properties	The best values	The values obtained for min (C)	Variations (%)	Type of the Change
Softness (Y)	2,97 kgf	3,01 kgf	+ 1,48	increase
Weft Breaking Strength (Akop)	637,62 N	595,95 N	- 6,50	decrease
Warp Breaking Strength (Ckop)	367,56 N	362,26 N	- 1,44	decrease
Hydrophilicity (H)	35,41 sec.	50 sec.	+ 41,19	increase

From the table, it is clear that, in minimizing the cost, hydrophilicity (H) took the value greater than the “best value” defined with the rate of 41.19 %, which means that if the cost is given priority, a considerable deterioration occurs in hydrophilicity level. In another word, increasing the hydrophilicity value (immersion time) decreases the hydrophilicity degree, depending on the test method adopted for the determination of the hydrophilicity. Similar evaluation can be performed for the case of softness. In the case of breaking strengths, however, it has been detected that increasing the measured value increased the strength of fabric as expected.

In this study, the cost and performance properties values obtained in model 1 are denoted as “optimum values”, since the cost optimization is preferential aim in the plants. Under the condition that the priorities (the features taken as objective) change in the established models, the deviations from these optimum values in the input and output parameters are also considered in the models. These variations or deviations as well as the magnitude of the changes concerned are given in Table-6 for each model in comparison with the results obtained from the model 1.

As it is seen from the table, when the solution results of models 1 and 2 are compared; it has been determined that if the minimization of the softness was aimed (model 2), the softness took the value less than that of obtained from the model no 1 with the rate of 1.45 % (a decrease), while Akop value increased with 5.5%. Apart from this, it was observed that warp breaking strength (Ckop) decreased with the rate of 1.28 % and hydrophilicity degree (H) remained as constant.

Table-6 The magnitude of changes occurred according to results of the model 1

Model No	Objective	Cost (C)		Softness (Y)		Weft Breaking Str. (Akop)		Warp Breaking Str. (Ckop)		Hydrophilicity (H)	
		Variation (%) ¹	Type of Change	Variation (%) ¹	Type of Change ²	Variation (%) ¹	Type of Change	Variation (%) ¹	Type of Change	Variation (%) ¹	Type of Change ²
2	min (Y)	0,17	increase	1,45	decrease	5,5	increase	1,28	decrease	- ³	- ³
3	max (Akop)	4,99	increase	8,1	increase	6,9	increase	1,46	increase	29	decrease
4	max (Ckop)	4,2	increase	7,29	increase	5,28	increase	1,46	increase	25,4	decrease
5	min (H)	4,99	increase	8,1	increase	6,9	increase	1,46	increase	29	decrease

*¹) The variations are defined by taking the solution values of model 1 aimed cost minimization as reference.

*²) The increase of softness value means the decrease of the fabric’s softness and the same case is valid for the hydrophilicity.

*³) The mentioned parameters remain constant (equal optimum values).

Generally, when the optimization of weft and warp breaking strength or hydrophilicity is purposed, rather than softness, it has been obtained that the softness value increased almost 7-8% comparing with the results given by the model 1, in another words, the stiffening of the fabric happens leading to an undesirable case. This case is attributed due to the fact that, in these models, the pile height increases nearly 10% comparing with the pile height value obtained from model 1. Consequently, increasing the pile height means increasing the fabric

thickness and in turn this may decrease the softness level depending on the principle of the test method adopted.

3. Conclusions

As a result of the solution of the established models covering only the single purpose optimization aiming to optimize each performance properties and production cost independently, the important findings have been given below.

1. It has been found that all of the established models have a nonlinear structure and “Global optimum solution” has been reached with these models adopted, which means that the best solution was obtained under the constraints considered.
2. The value belonging to the objective function (a value for the parameter being optimized) is denoted as the “best value” from which the property being optimized should take under the constraint defined. In addition to this, the cost and performance properties values obtained in model 1 are accepted as “optimum values”, since the cost optimization is preferential aim in the plants.
3. It can be seen that while the priorities of the objective for the models are changed and the limit values of the constraints remain constant, the values of the physical properties will take the values very close to each other. However, it was concluded that only weight and pile height values showed remarkable changes.
4. According to the results obtained by evaluating the solution reports of all models, it was shown that remarkable variations occurred in weft breaking strength and hydrophility values under the conditions that the objective of the model was changed while the related constraints remained as constant. These variations have been thought to be caused from the changes in weight and pile height values.
5. When the production cost was the main aim in optimization procedure, a considerable deterioration in fabric performance properties was detected of which the maximum remarkable variation being in hydrophility value with the rate of 41.1%.
6. It was designated that the cost value obtained with model aiming only softness minimization was almost equal with the optimum cost value (the result of model 1), whereas the cost values determined with model no 3 (aiming the weft breaking strength maximization) and with model no 5 (aiming the hydrophility minimization) took the values greater than the optimum value given by model 1 with the rate of 4.99%. In addition to this, the cost value obtained from the model no 4 (the aim is the maximization of the warp breaking strength) was increased with 4.2 %, relating to the model 1.
7. When the maximization of weft breaking strength (A_{kop}) was aimed, it was observed that the cost increased with the rate of 4.99% and other performance properties were affected positively (except softness) with reference to model 1. Especially the hydrophility value (immersion time) took the value less than the optimum cost value with 29%, which means that if the A_{kop} is given priority, a considerable improvement occurs in hydrophility level.
8. It has been determined that if the maximization of the warp breaking strength (C_{kop}) was aimed, the cost increased with 4.2% comparing with the result of the model 1, whereas C_{kop} value took the value greater than that of the model 1 with the rate of only 1.46%. However, this model seems imperferable since the improvement obtained in warp breaking strength was not coincided with the increase in the cost and the deterioration detected in softness value with the rate of 7.2%.
9. If the optimization of the weft-warp breaking strengths or hydrophility is aimed, it has generally been inferred that stiffening was occurred in the handle or softness of the fabric under investigation.

10. The remarks outlined in this paper and the results concerning the multi objective models or the theoretical approach adopted to predict the necessary physical properties and cost value for the production of towels having certain performance properties, would be considered as a design tool for towel producers to estimate necessary data concerning the physical properties and the production cost without trial production process.

4. References

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